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(Supersedes IMR No. 586)

YAWSONDE FLIGHTS OF 155MM NON-CONICAL
BOATTAIL PROJECTILES AND THE 155MM M549
PROJECTILE AT TONOPAH TEST RANGE--OCTOBER 1977

Anders S. Platou

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (1cb) As part of the BRL program to develop the non-conical boattail projectile, twenty 155mm projectiles were fired from an M185 gun tube on 18 and 21 October 1977 at the Sandia Corporation, Tonopah Test Range, Nevada. This is the second phase of a planned three phase test program at Tonopah on the non-conical boattail projectiles. The report describes the experimental plans and presents the data records and some of the results obtained during the projectile flights.		

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I. INTRODUCTION

The BRL program to develop the non-conical boattail projectile requires the firing of approximately one hundred 155 mm projectiles and twenty-two 105 mm projectiles under various flight conditions. During each flight various aeroballistic information is recorded for later analysis. So far, thirteen 155 mm projectiles and twenty-two 105 mm projectiles have been fired at APG for charge assessment, mechanical integrity, and aerodynamic characteristics, six 155 mm projectiles have been fired at Nicolet, Canada, under minimum stability conditions and thirty-three 155 mm projectiles have been fired at the Tonopah Test Range, Nevada, at various flight conditions. All of these firings have been reported^{1,2,3} except for the last thirteen fired at Tonopah on 18 and 21 October 1977. This report presents the experimental plans, and the in-flight data records on these thirteen projectiles plus seven additional 155 mm M549 projectiles used as reference projectiles. These twenty projectile flights are the second phase of three to be flown at Tonopah.

II. TEST SITE AND FACILITIES

The Tonopah Test Range and facilities are the same used during the Phase I firings and are described in detail in reference 3.

III. CONFIGURATIONS, TEST PROGRAM, AND INSTRUMENTATION

During the week of 16 October 1977, twenty 155 mm projectiles were fired from an M185 gun tube. Three projectile configurations were flown as listed below.

1. M549 RAP Projectile with rocket on or off (Figures 1 and 2).
2. Non-Conical Boattail Projectile A (NCB-A) (Figures 2 and 3).

1. *Anders S. Platou, "An Improved Projectile Boattail. Part IV.," ARBRL-MR-02826, April 1978, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland. AD BB027520L.*
2. *John H. Whiteside, "Transonic Tests of the 155mm Non-Conical Boat-tail Projectile A and the 8-Inch XM650E4 and EBVP Projectiles at Nicolet, Canada, During January-February 1977," ARBRL-MR-02809, January 1978, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland. AD B027297L.*
3. *Vural Oskay and Anders S. Platou, "Yawsonde Tests of 155mm M549 Non-Conical Boattail Projectile at Tonopah Test Range," BRL Memorandum Report in preparation.*

3. Non-Conical Boattail Projectile B (NCB-B) (Figures 4, 5, and 6).

The model physical characteristics are given in Table I, and the test program is given in Table II. Each projectile was instrumented with a yawsonde just prior to the launch so that the angular yawing motion of the projectile during the flight was recorded. Radar was used to track each projectile to provide trajectory and velocity records. Impact coordinates were obtained from ground surveys.

The projectiles NCB-A and M549 were launched using standard copper rotating bands and required no preliminary tests. The NCB-B projectiles used a plastic discarding rotating band which required some development of the design. The final design used on the NCB-B projectile is shown in Figure 5. The plastic Eurethane was molded onto the triangular boattail with three (one on each triangular surface) aluminum keys used to keep the projectile from sliding axially with respect to the plastic during the projectile ramming process. The exterior of the plastic was then machined to the dimensions shown in Figure 7. At propellant ignition the plastic moves forward with respect to the projectile, breaking into small pieces as it becomes compacted between the projectile and the gun tube rifling grooves. This action brings the projectile spin up to the gun twist value, thereby stabilizing the projectile in flight. After leaving the muzzle the small pieces of plastic fall to the ground and the aluminum keys are thrown away by centrifugal force.

IV. RESULTS AND CONCLUSIONS

1. The log of the twenty flights of the Phase II firings is given in Table III.

2. Muzzle velocity variations (642.5 to 659.3 m/s) for the nine NCB-A projectiles is reduced from those observed during the corresponding Phase I firings (625.1 to 658.4) but is still higher than desired. Muzzle velocity variations during the firing of the five M549 RAP projectiles is much less (245.3 to 247.5 m/s). This is apparently due to use of a plastic obturator ring to create a better gas seal for the propelling gases. It is understood that this seal is used on most 155 mm projectile firings and it should be used with the NCB-A projectiles.

3. The first maximum yaw values ($2\frac{1}{2}^\circ$ to 5°) had less variation and were lower than during the corresponding Phase I tests (1.6° to 9°). This is probably due to increasing the rear portion of the boattail diameter to within .25 mm of the gun bore. During the manufacture of the NCB-A and NCB-B projectiles, the main boattail diameter had been undercut by .76 mm, but has been corrected on all non-conical boattailed projectiles fired since Phase I (Figures 3 and 6) by welding aluminum pads on the rear portion of the boattail and machining to within .25 mm

of the gun bore diameter. Machining the whole boattail diameter to tighter tolerances should lower the first maximum yaw values even further.

4. The yawsonde records show all of the projectiles had stable flights (Figures 8 to 39). The first maximum yaw of the NCB-A projectiles was slightly higher ($2\frac{1}{2}^{\circ}$ to 5°) than the M549 RAP (rocket off), but it is not believed that this small yaw will deter the flight performance. Only the first portion of the yawsonde records for the 18 October 1977 flights have been processed so far. Unless the need arises, the later portion of these flights will not be processed for the aerodynamic characteristics of the NCB-A and M549 are known (references 1 and 4).

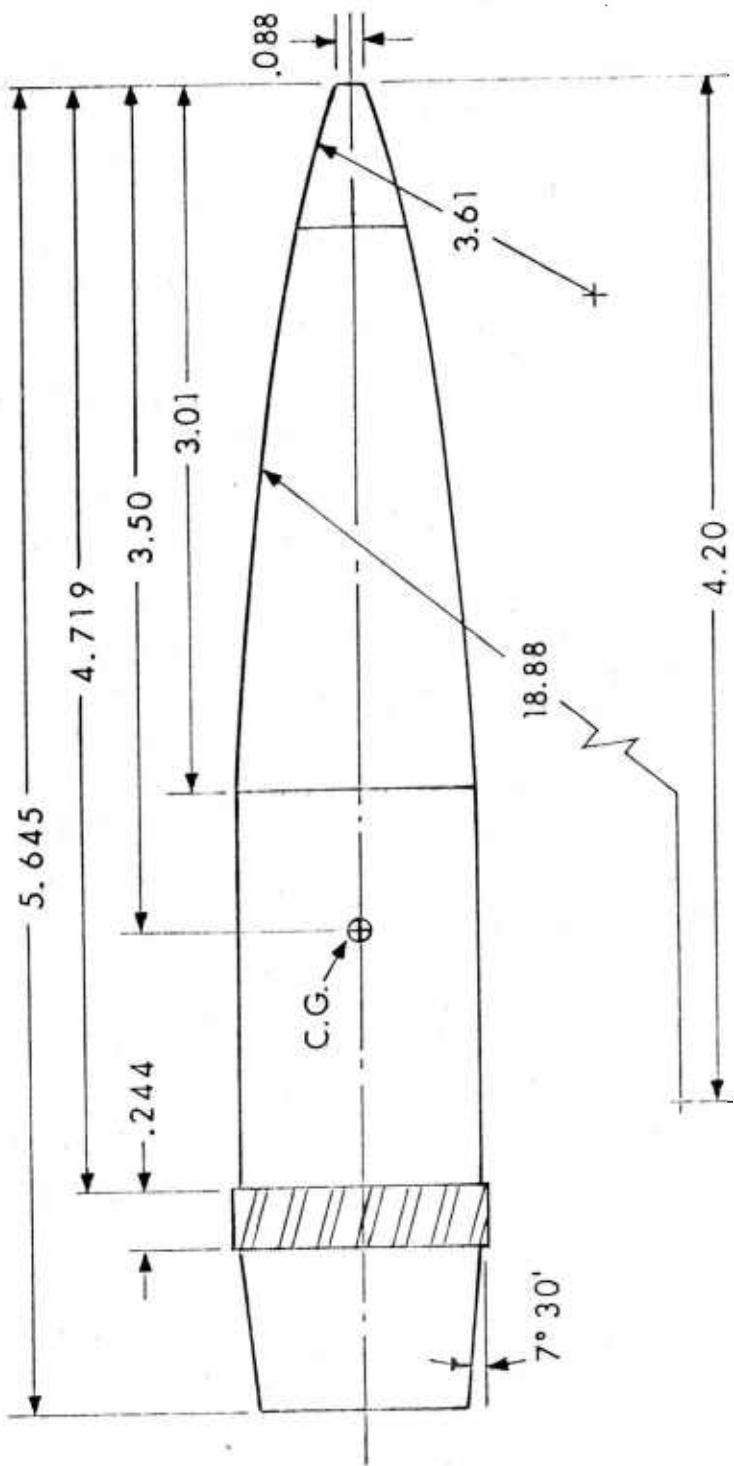
5. The two M549 RAP projectiles with rocket on were fired for general interest and are not directly associated with the non-conical boattail testing. Their yawsonde records (Figures 31 to 34) show stable flight; however, the spin increase (in spite of the uncantered axial nozzle) during the rocket on portion of the flight ($t = 7$ seconds to 10 seconds) is not clearly understood. This phenomena has been observed before on other large caliber rocket assisted flights. The blanking of the telemetered yawsonde signal during the rocket on portion of the flight has also been observed before.

6. The four NCB-B projectiles which were launched at transonic speeds ($M \approx 1.05$) flew with a 5° limit cycle (Figures 35 to 39) similar to those observed during the NCB-A transonic launch flights (references 2 and 3). Also, the NCB-B angular motion recovered from large artificially induced first maximum yaw (Figure 39) similar to the NCB-A projectile. The aerodynamic characteristics of the NCB-B projectile will be computed from these yawsonde records as soon as possible.

7. Impact, deflection, and muzzle velocity are given in Table IV. Table IV also gives the impact data for the NCB-A and the M549 projectiles corrected to the listed muzzle velocities and the resulting dispersion values.

8. On all of the spin plots PHI DOT is the Eulerian spin of the projectile and the spin about the principle body axis at any given time is essentially the average of PHI DOT.

4. R. W. Kline, W. R. Herrmann, and V. Oskay, "A Determination of the Aerodynamic Coefficients of the 155mm, M549 Projectile," Picatinny Arsenal Technical Report No. 4764, November 1974. AD B002073L.



ALL DIMENSIONS IN CALIBERS
1 caliber = 15.47 mm

Figure 1. The 155mm M549 Projectile

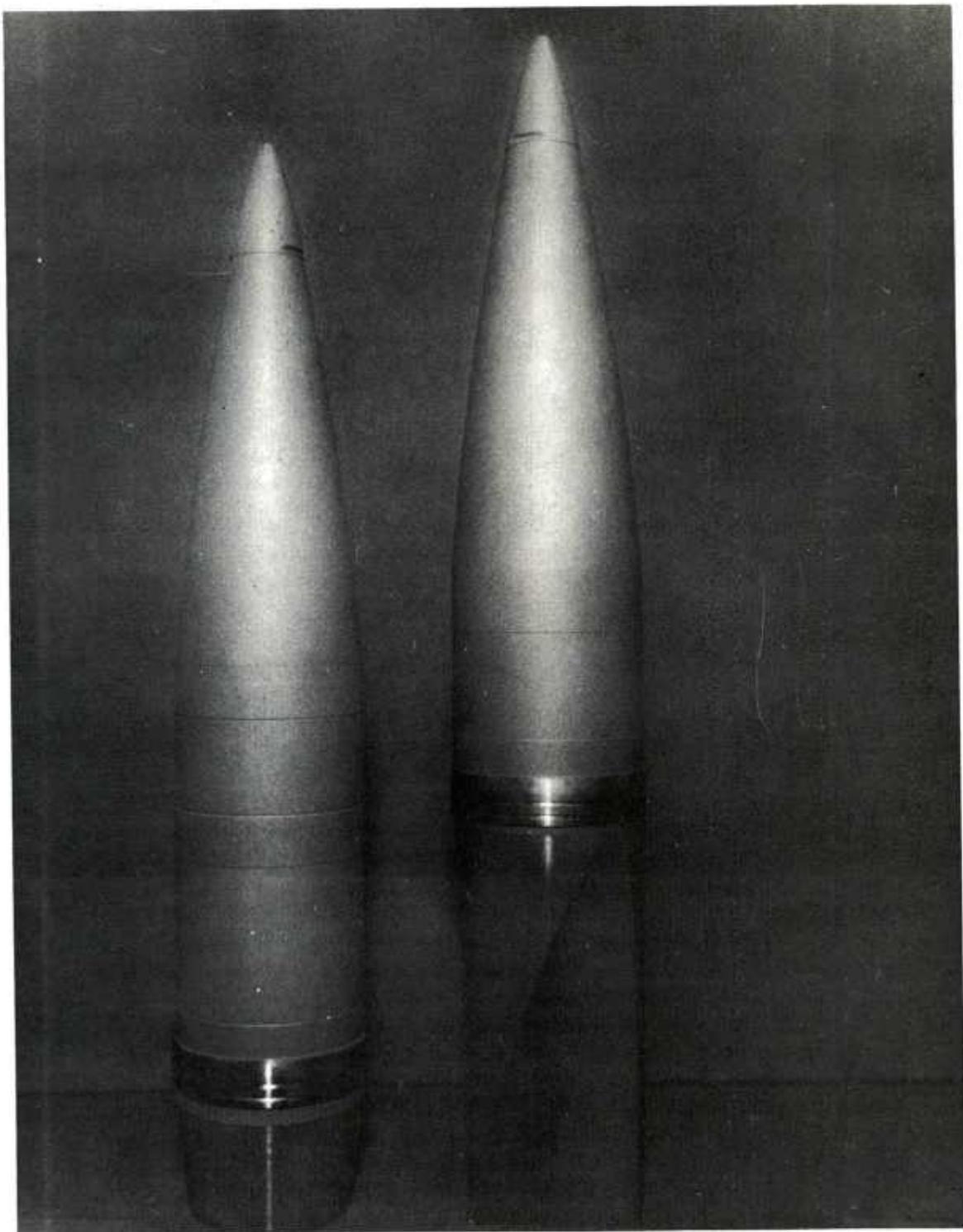
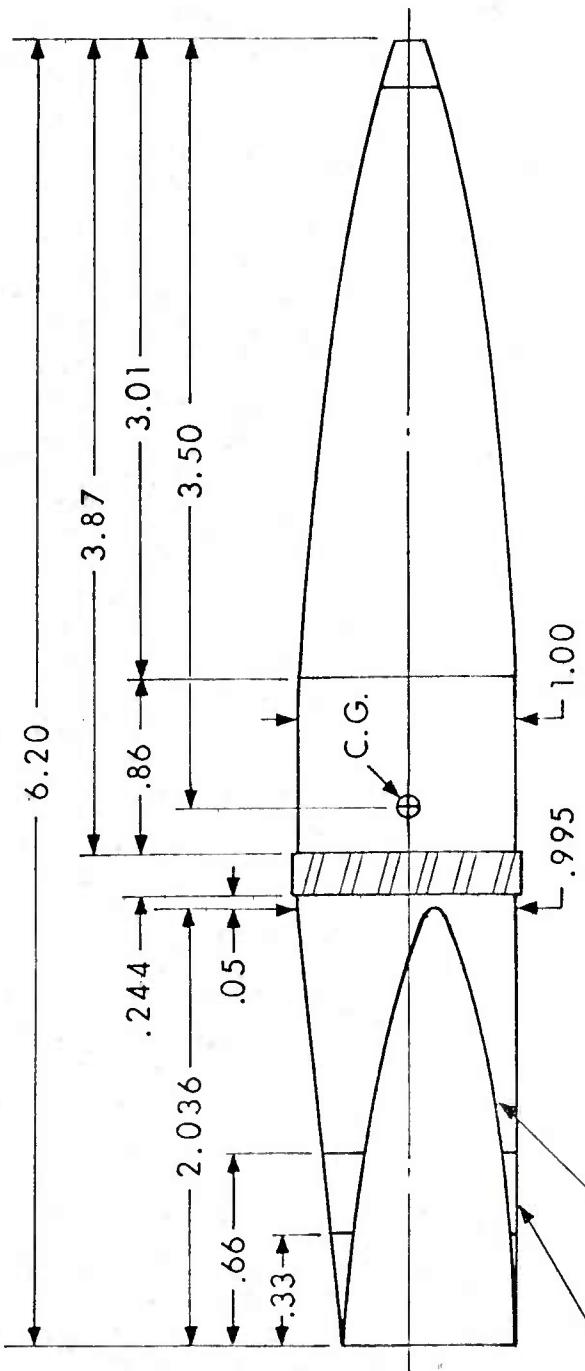


Figure 2. The M549 and the NCB-A Projectiles



7° TRIANGULAR BOATTAIL
R.H. SPIRAL-1 TURN IN 20 CALIBERS
BOATTAIL DIAMETER INCREASED TO
1.00 CALIBER IN THIS REGION

THIS CONFIGURATION IS THE
SAME AS THE M549 FORWARD
OF THE ROTATING BAND

ALL DIMENSIONS IN CALIBERS
1 caliber = 154.7 mm

Figure 3. The Non-Conical Boattail Projectile--NCB-A

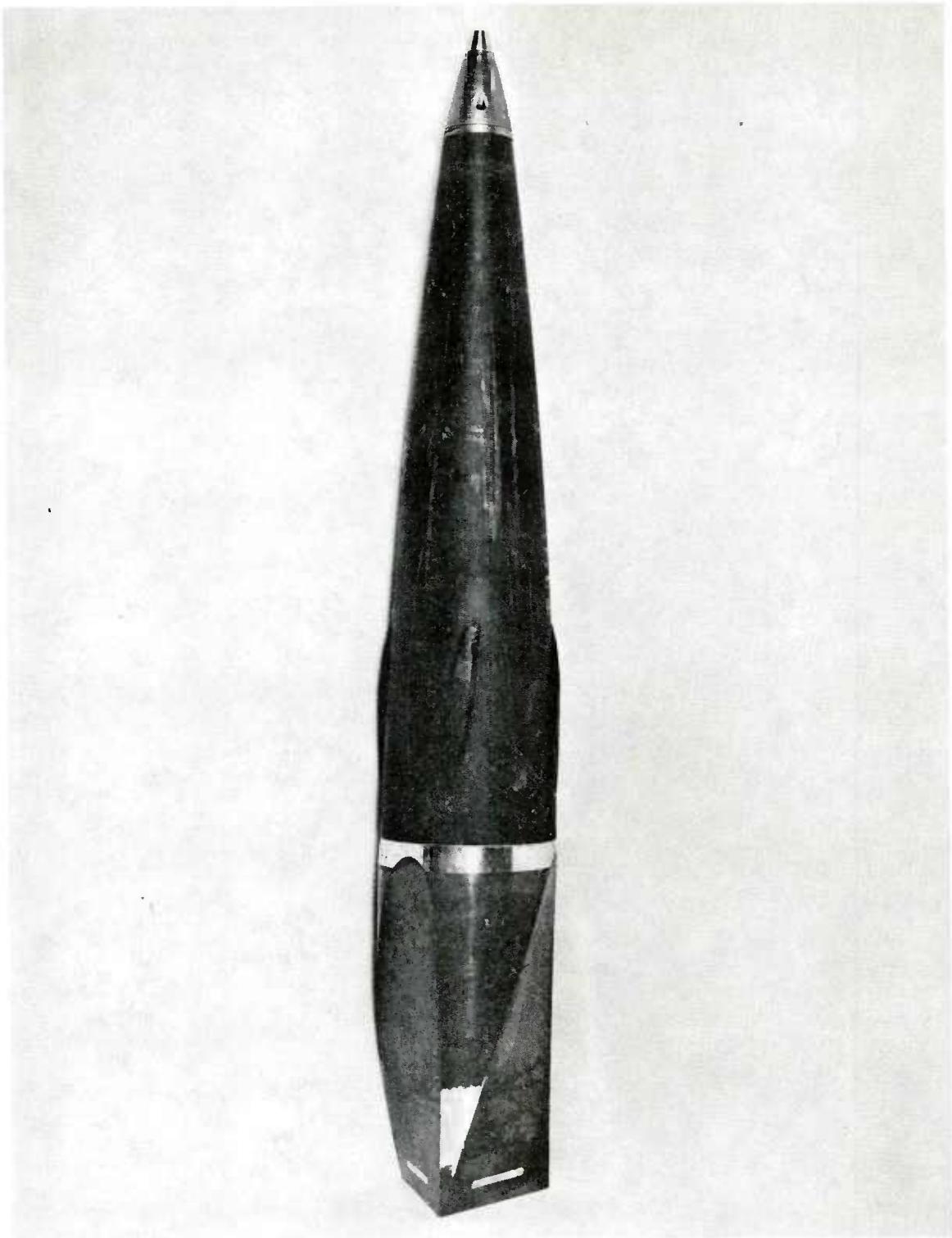


Figure 4. The NCB-B Projectile Without the Discarding Rotating Band

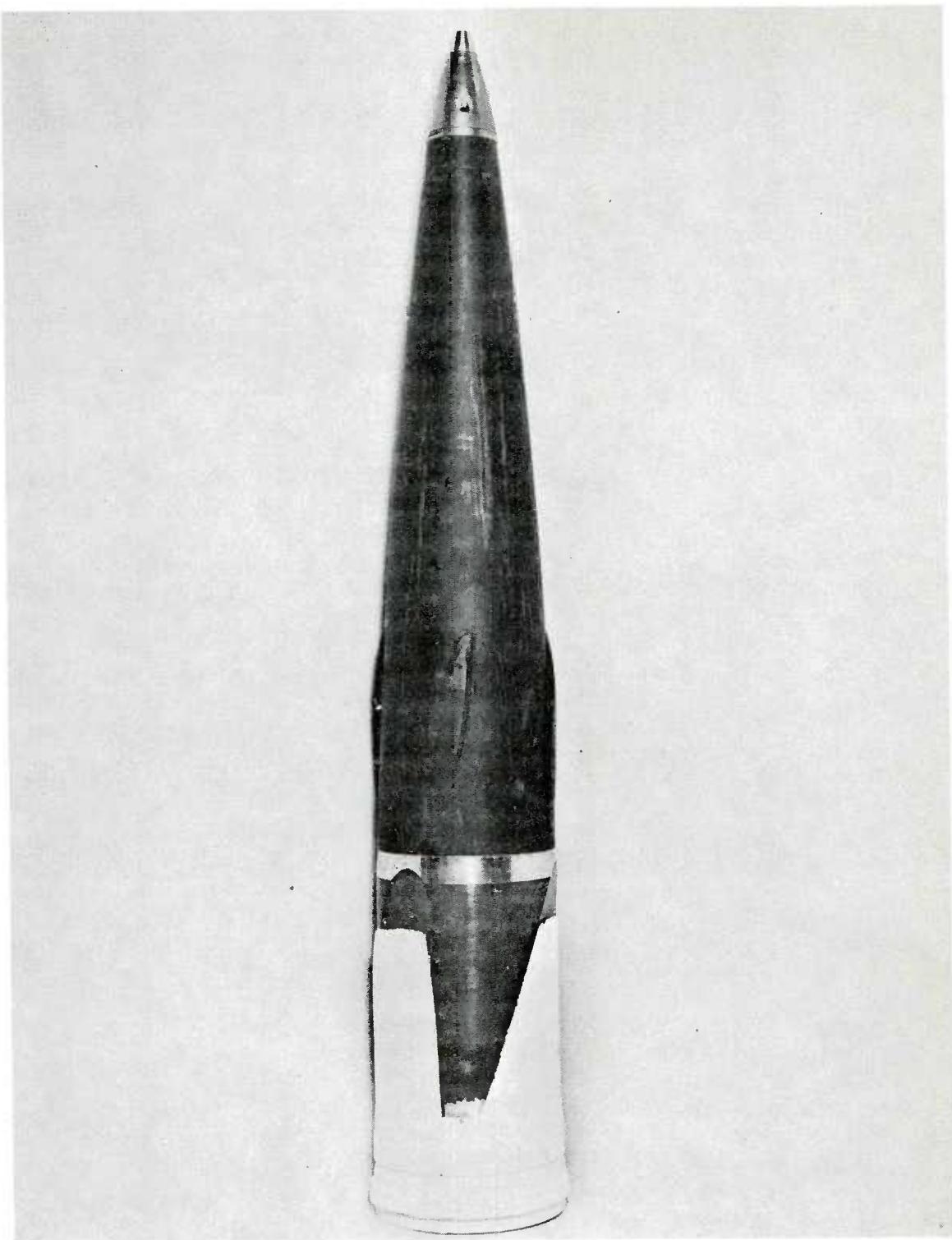


Figure 5. The NCB-B Projectile With the Discarding Rotating Band

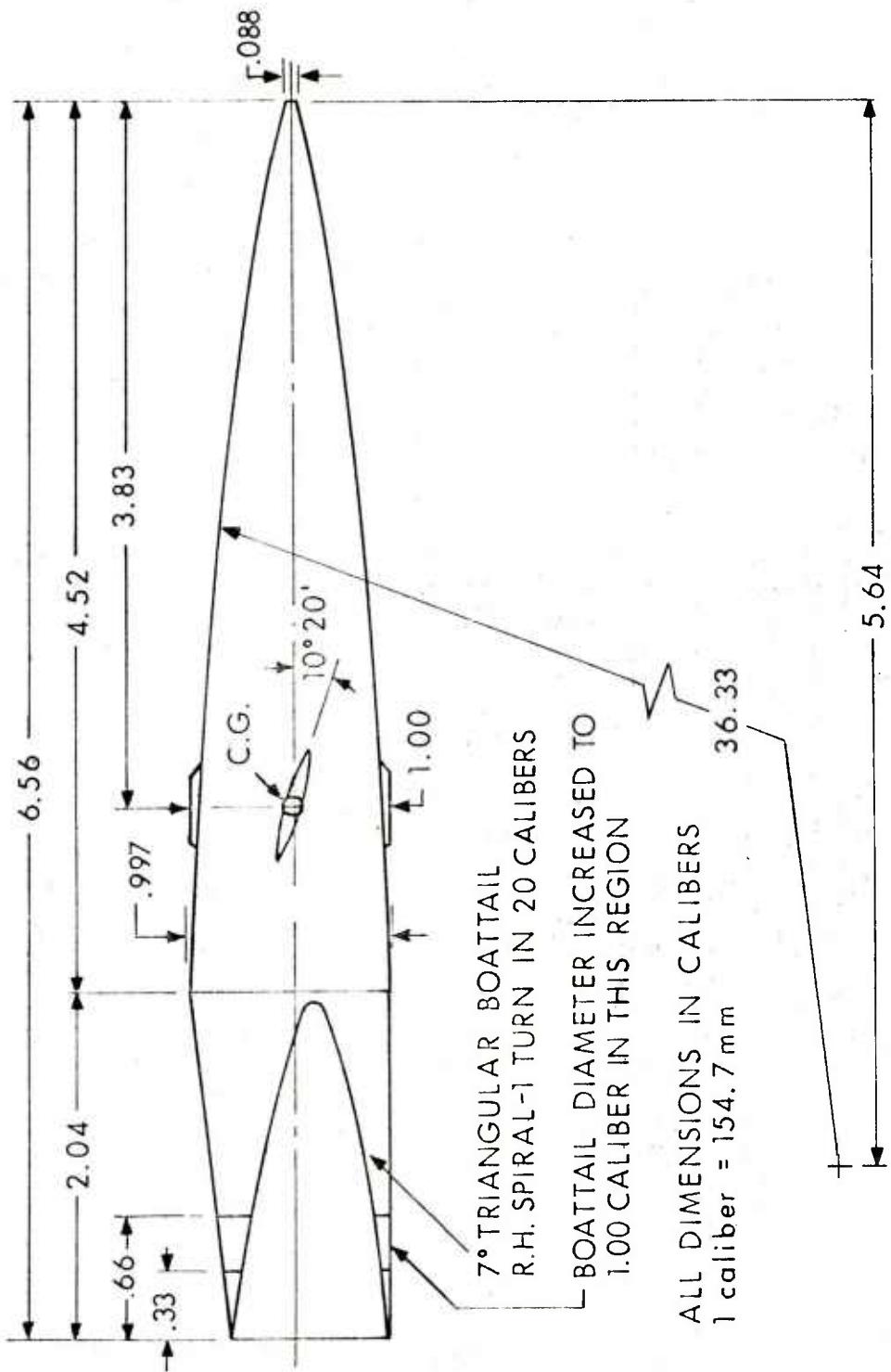


Figure 6. The Non-Conical Boat-tail Projectile--NCB-B

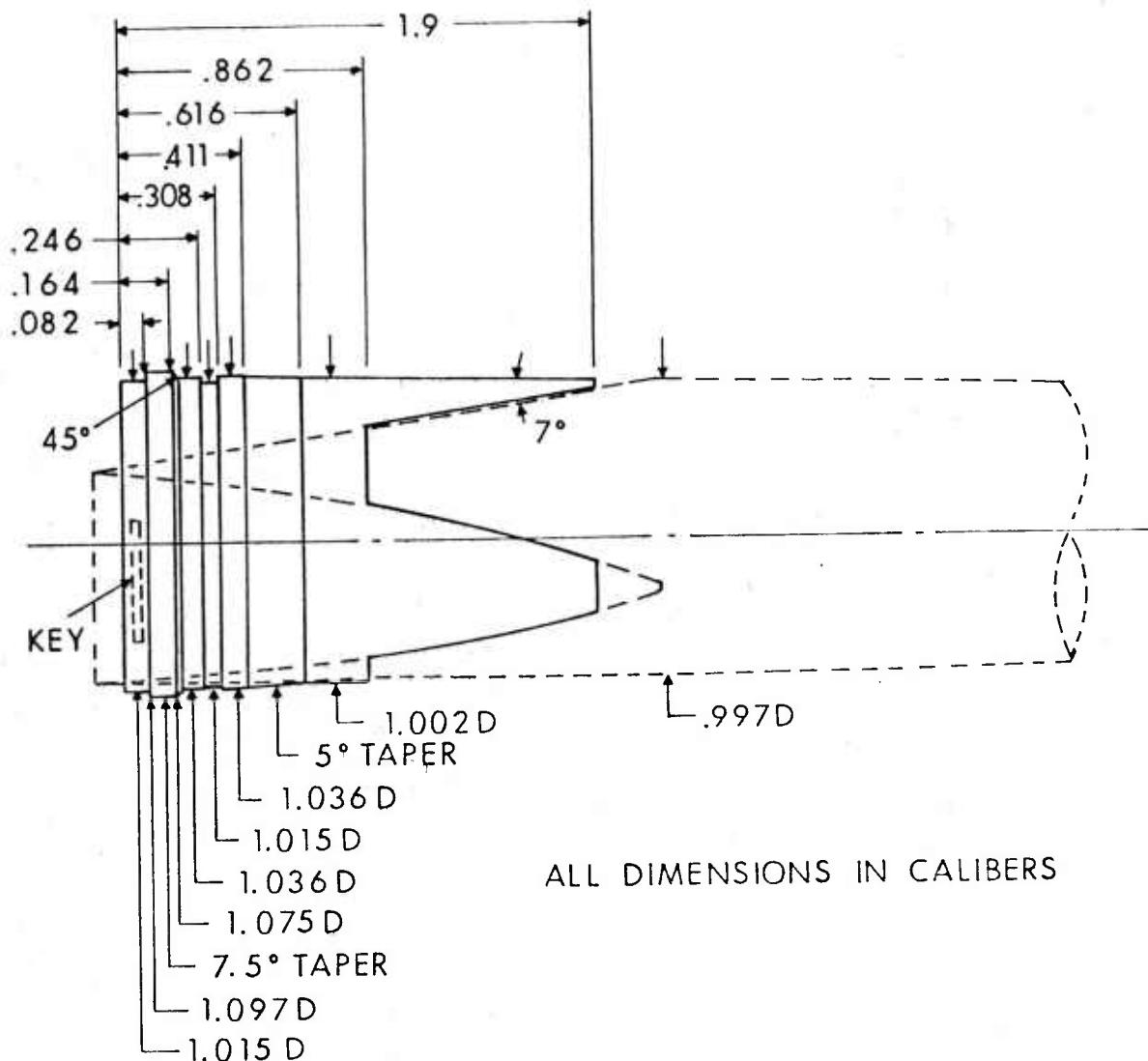


Figure 7. The External Dimensions of the Plastic Discarding Rotating Band

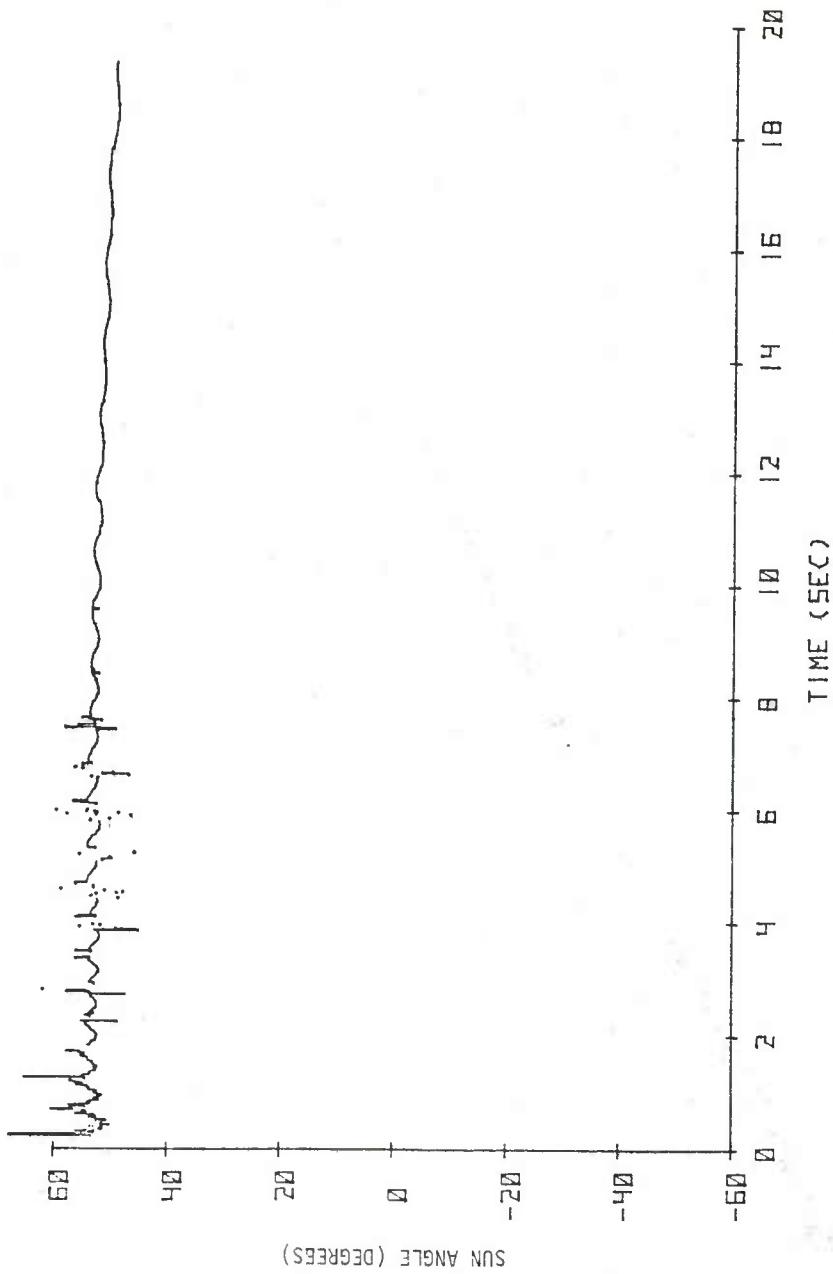


Figure 8. The Yawing Motion of the NCB-A Projectile Round No. 1

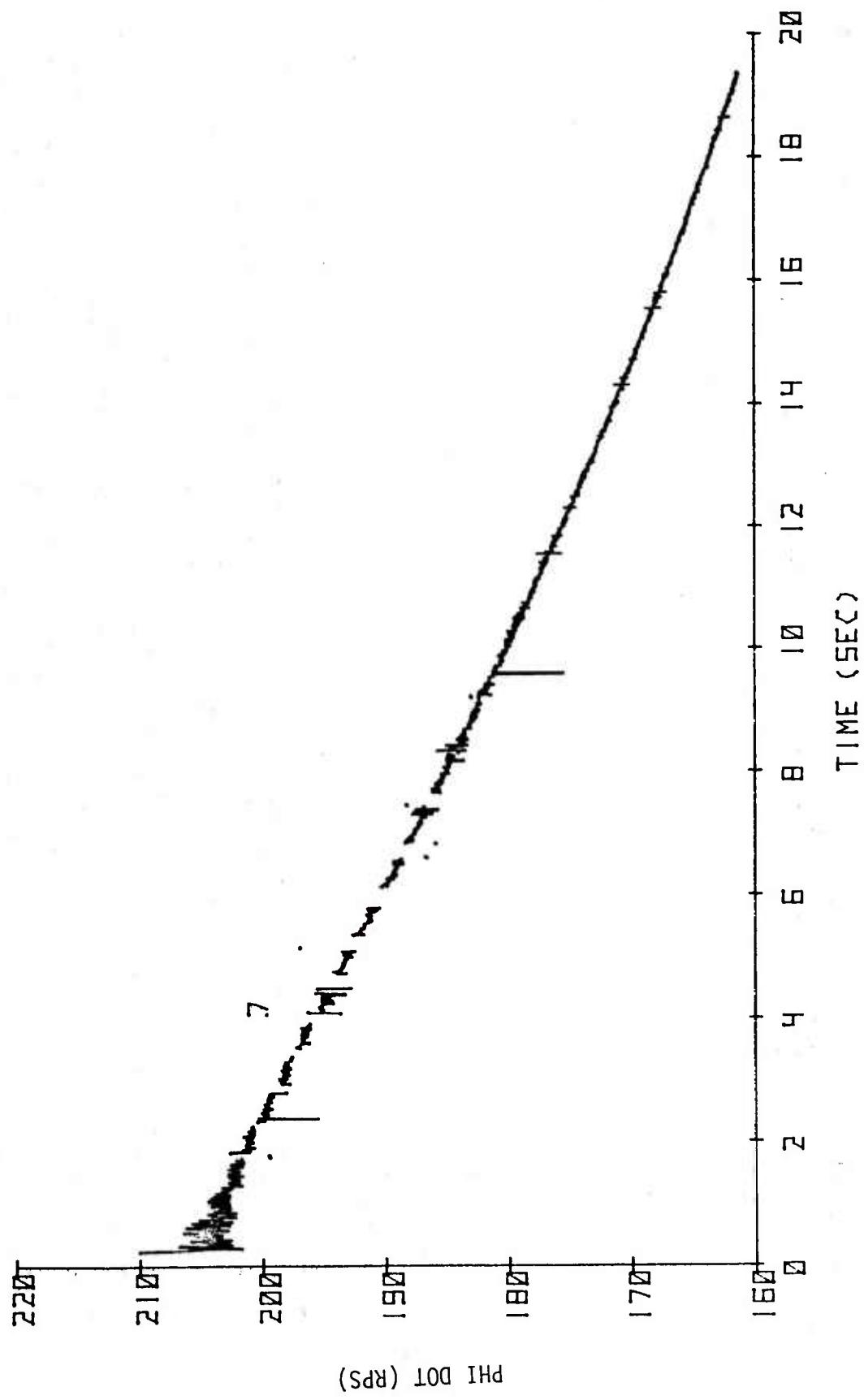


Figure 9. The Spin Motion of the NCB-A Projectile Round No. 1

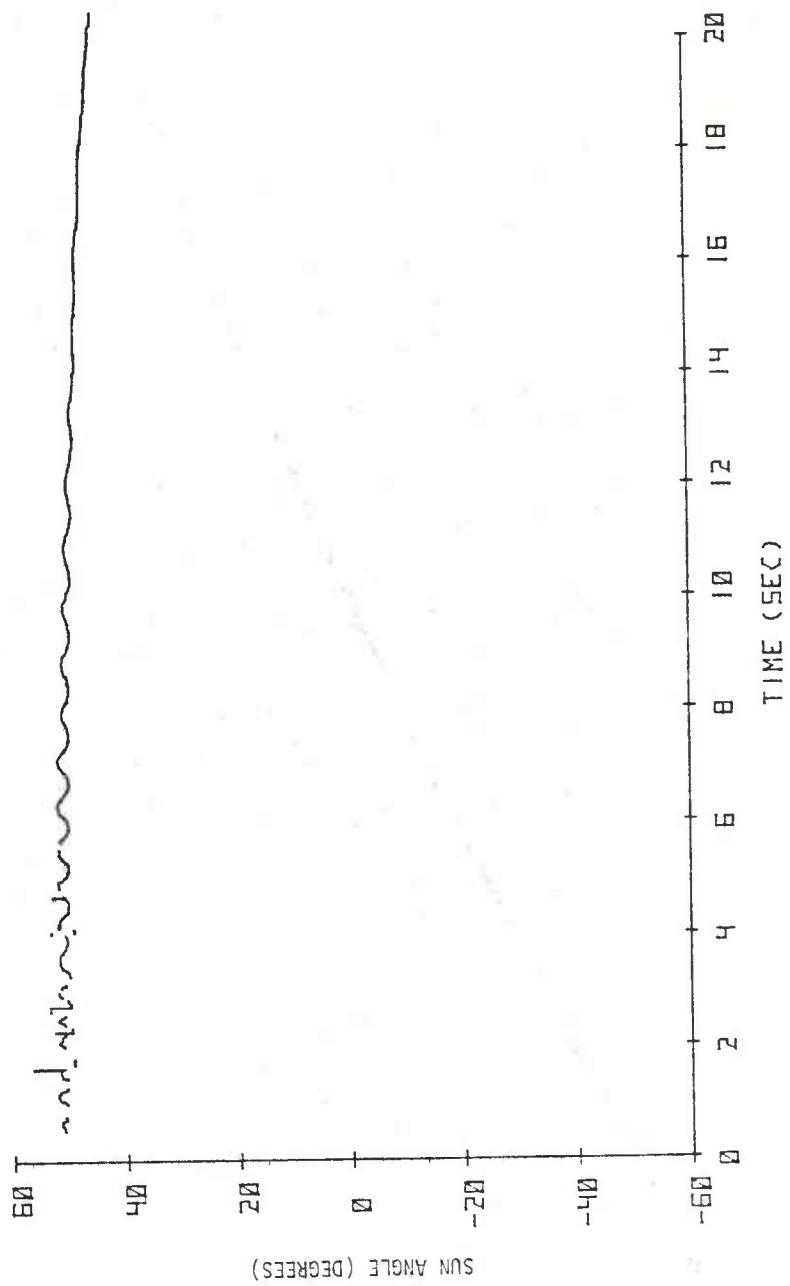


Figure 10. The Yawing Motion of the NCB-A Projectile Round No. 2

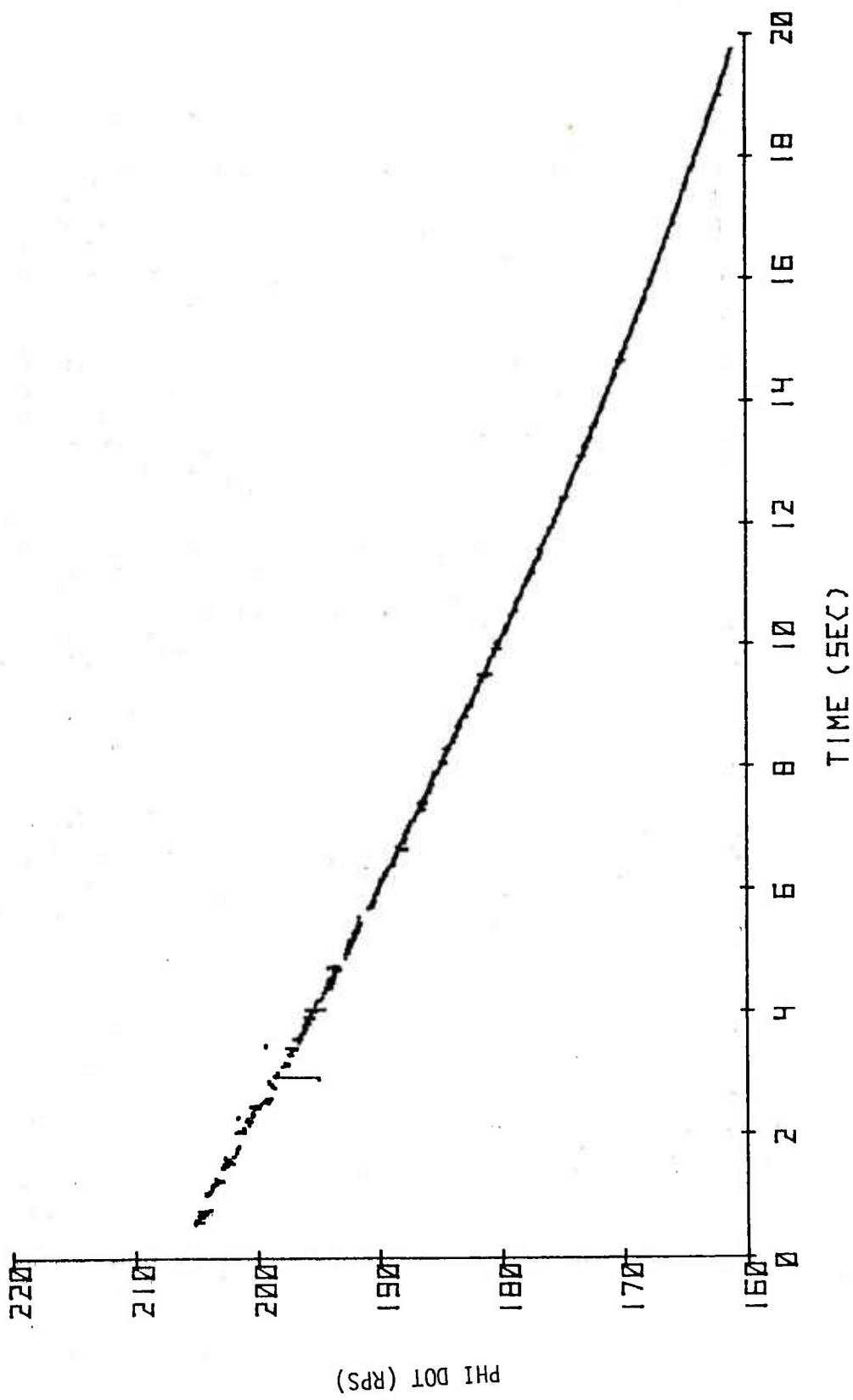


Figure 11. The Spin Motion of the NCB-A Projectile Round No. 2

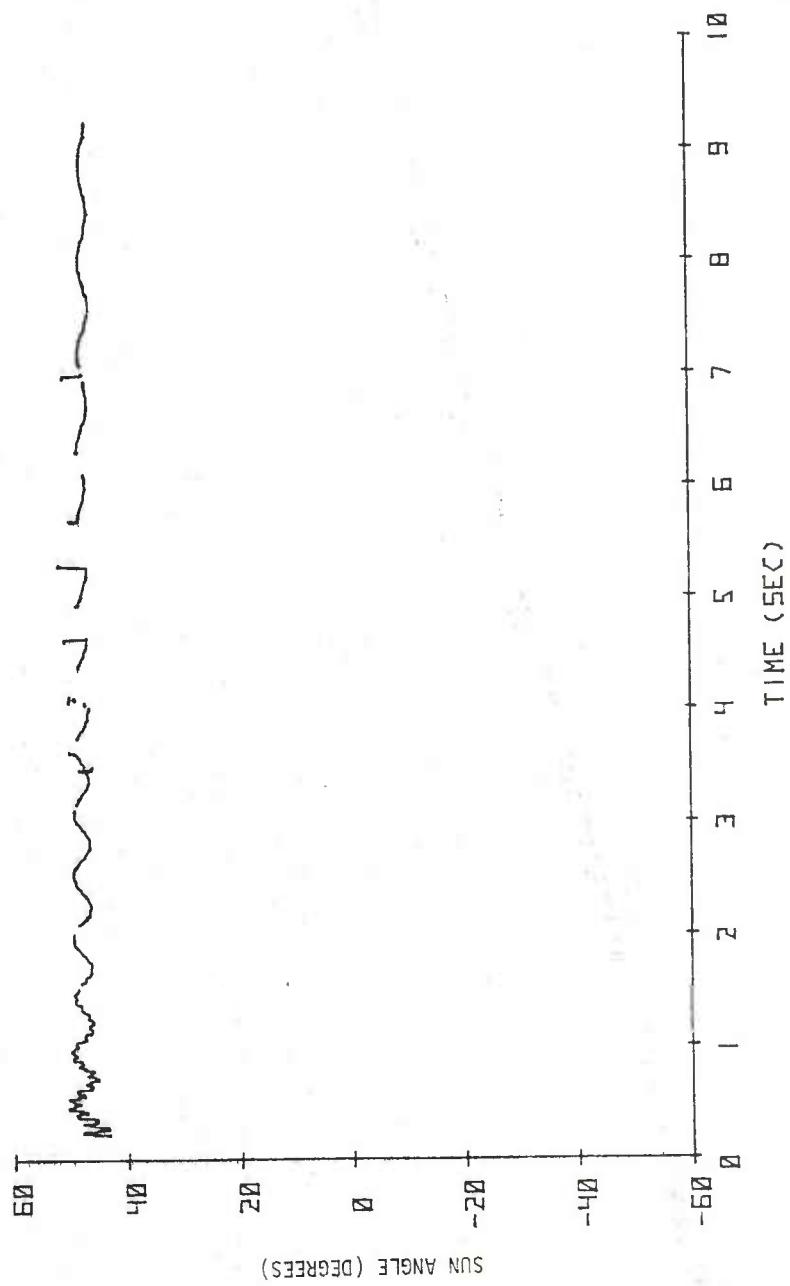


Figure 12. The Yawing Motion of the NCB-A Projectile Round No. 3

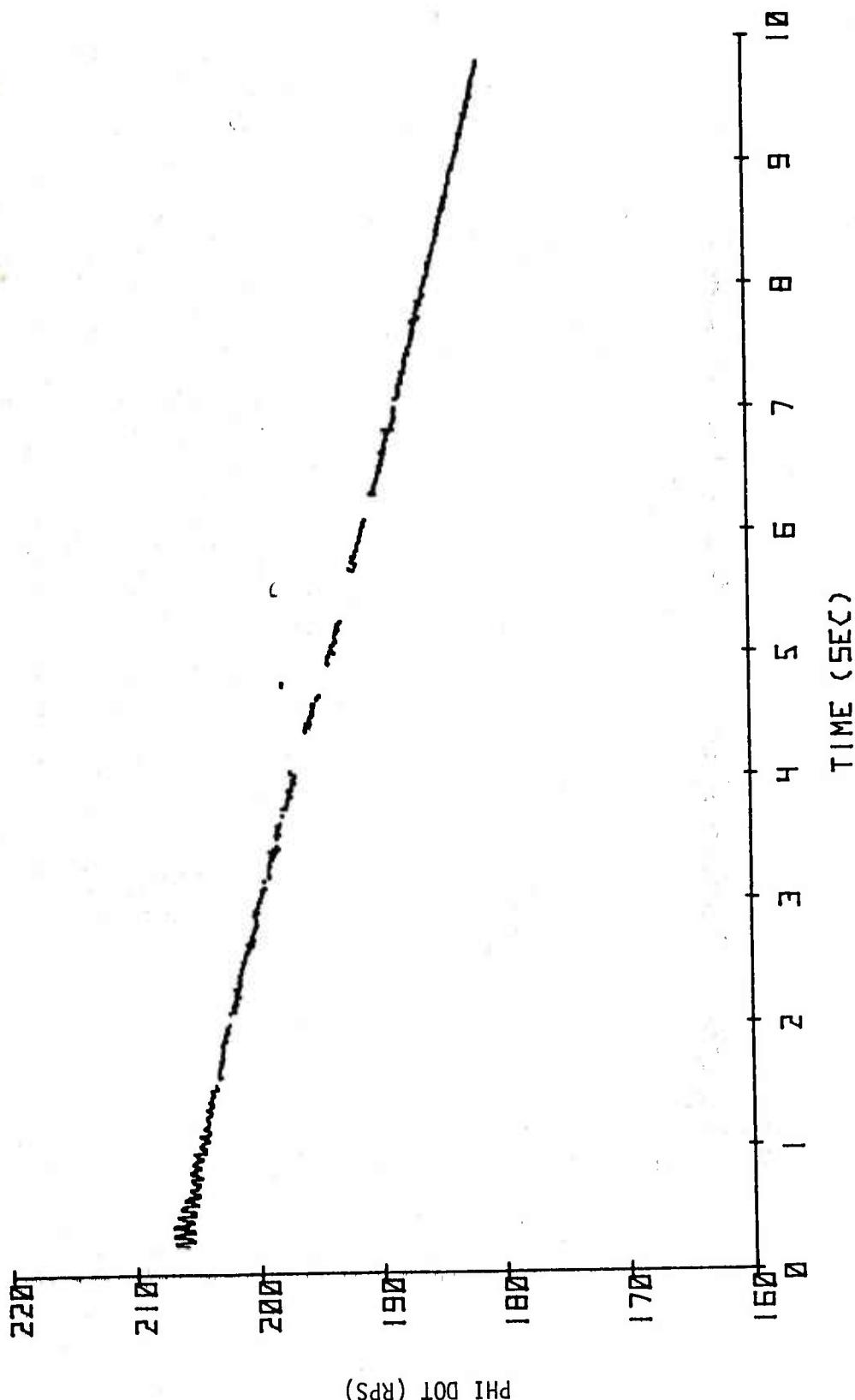


Figure 13. The Spin Motion of the NCB-A Projectile Round No. 3

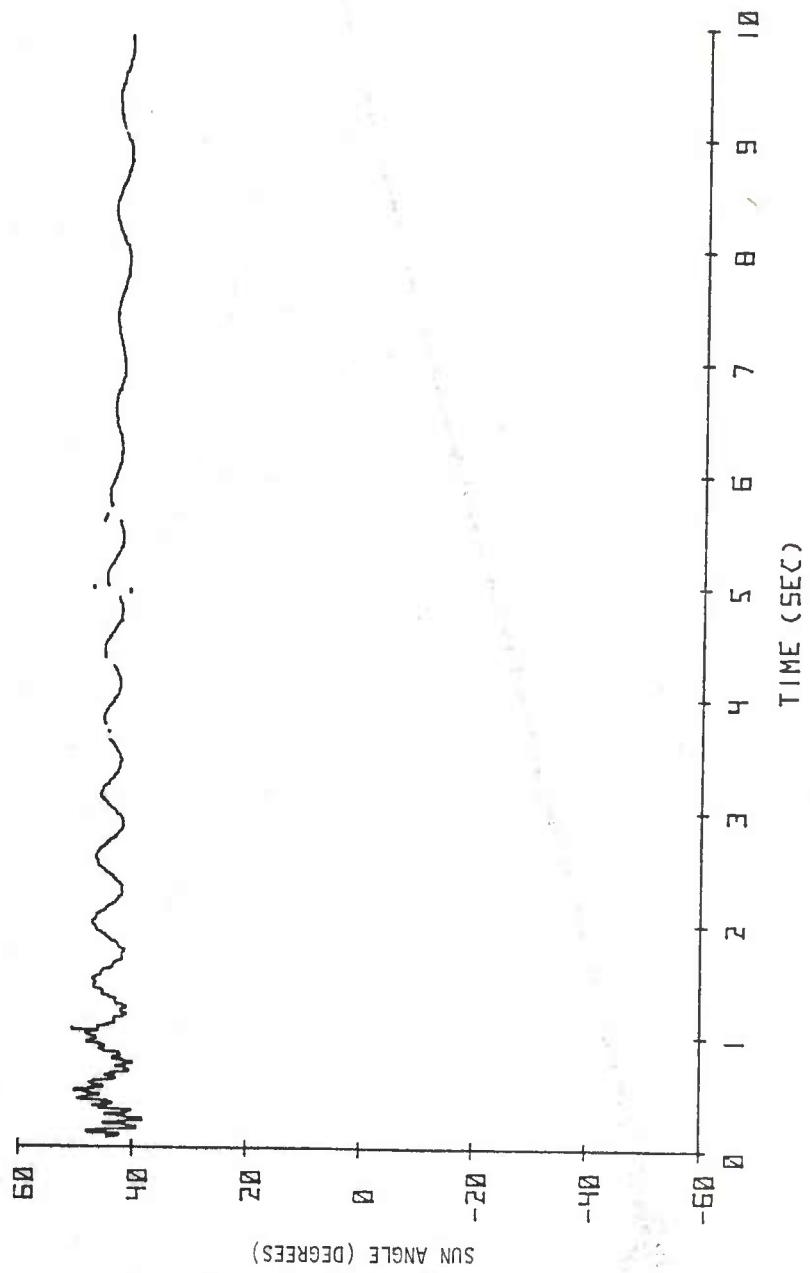


Figure 14. The Yawing Motion of the NCB-A Projectile Round No. 4

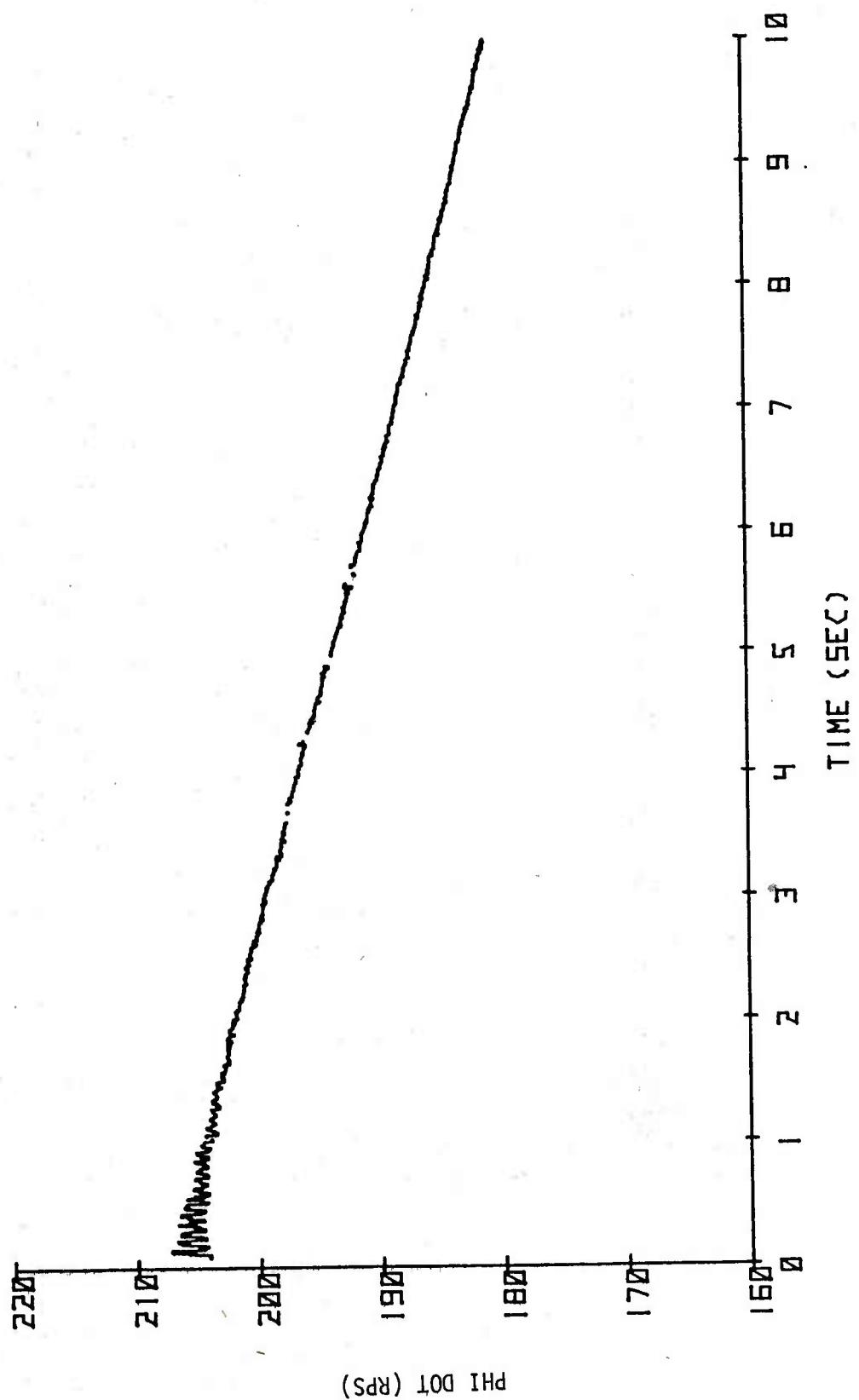


Figure 15. The Spin Motion of the NCB-A Projectile Round No. 4

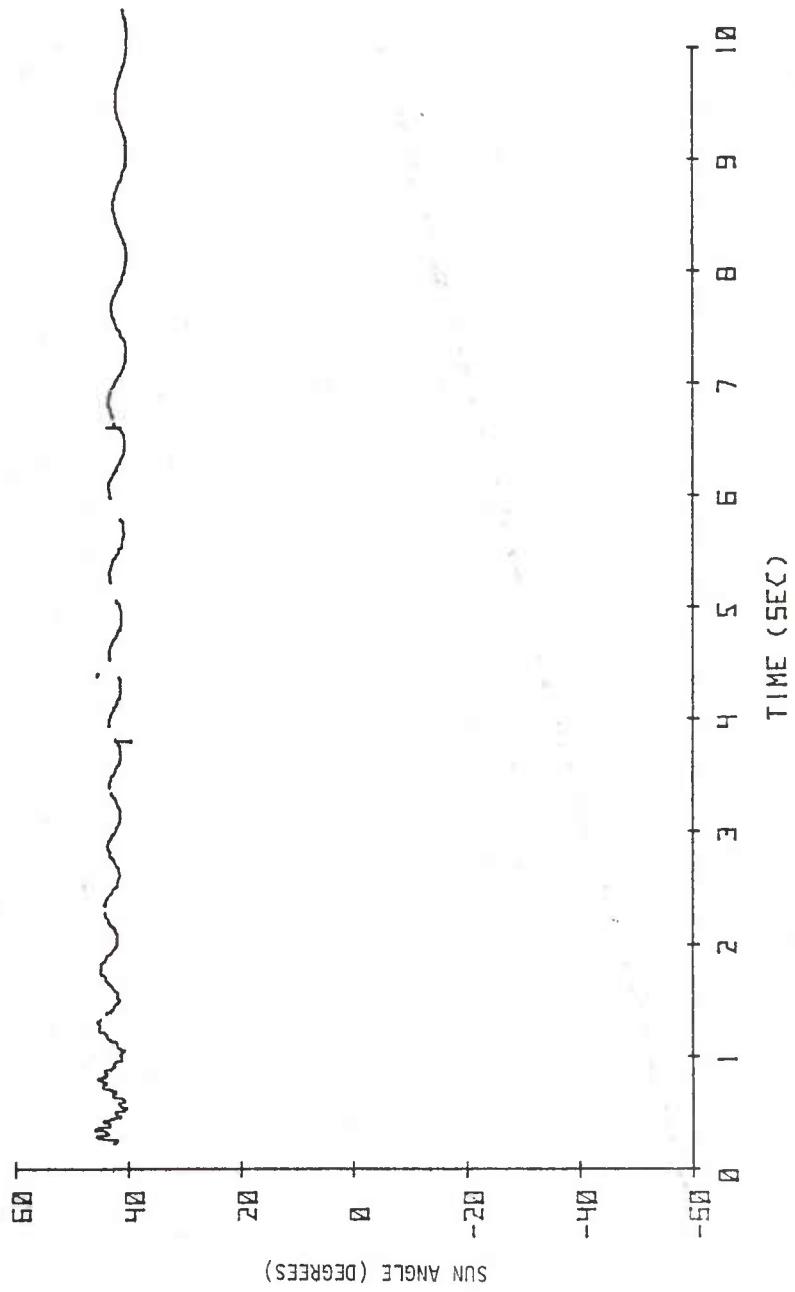


Figure 16. The Yawing Motion of the NCB-A Projectile Round No. 5

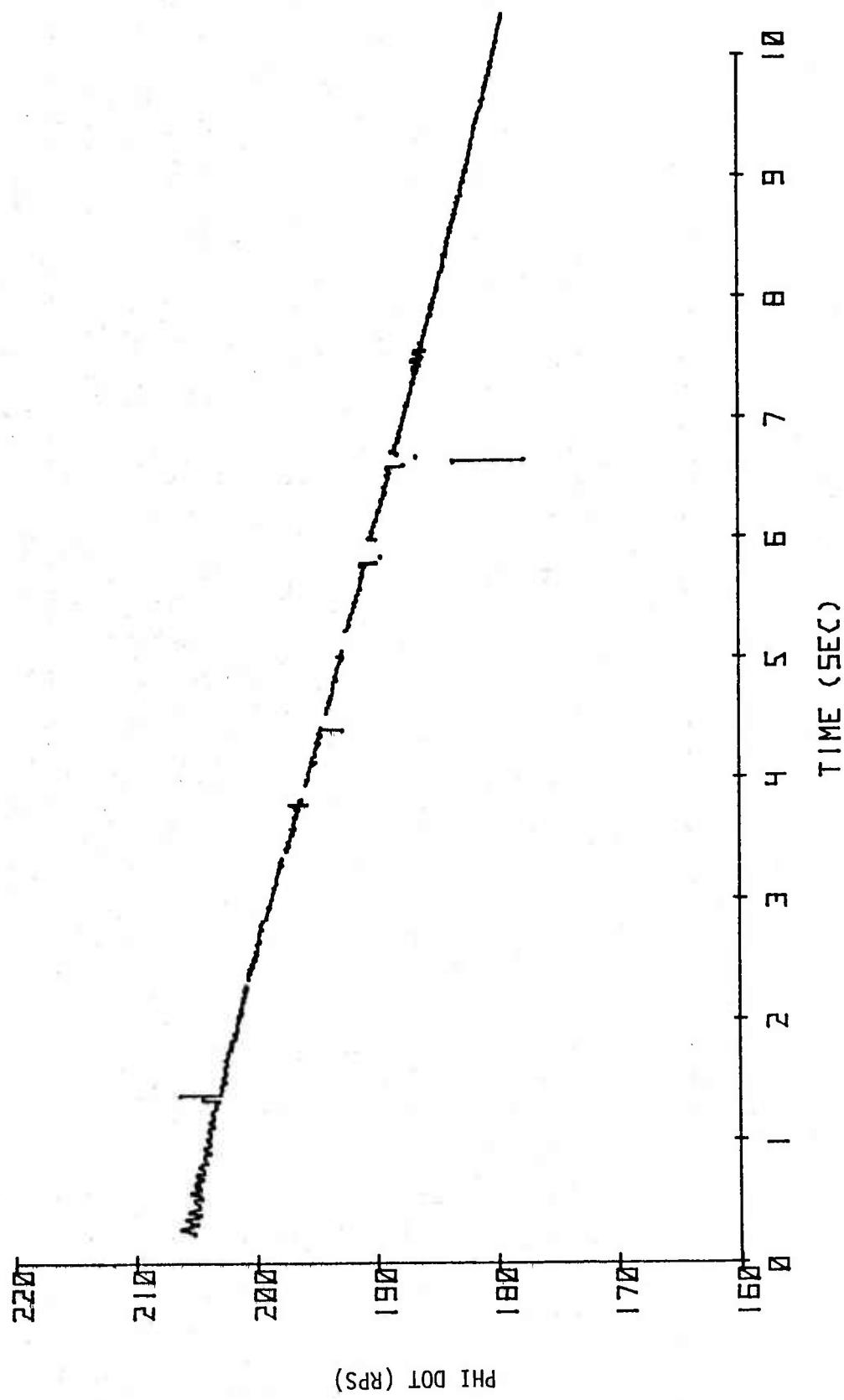


Figure 17. The Spin Motion of the NCB-A Projectile Round No. 5

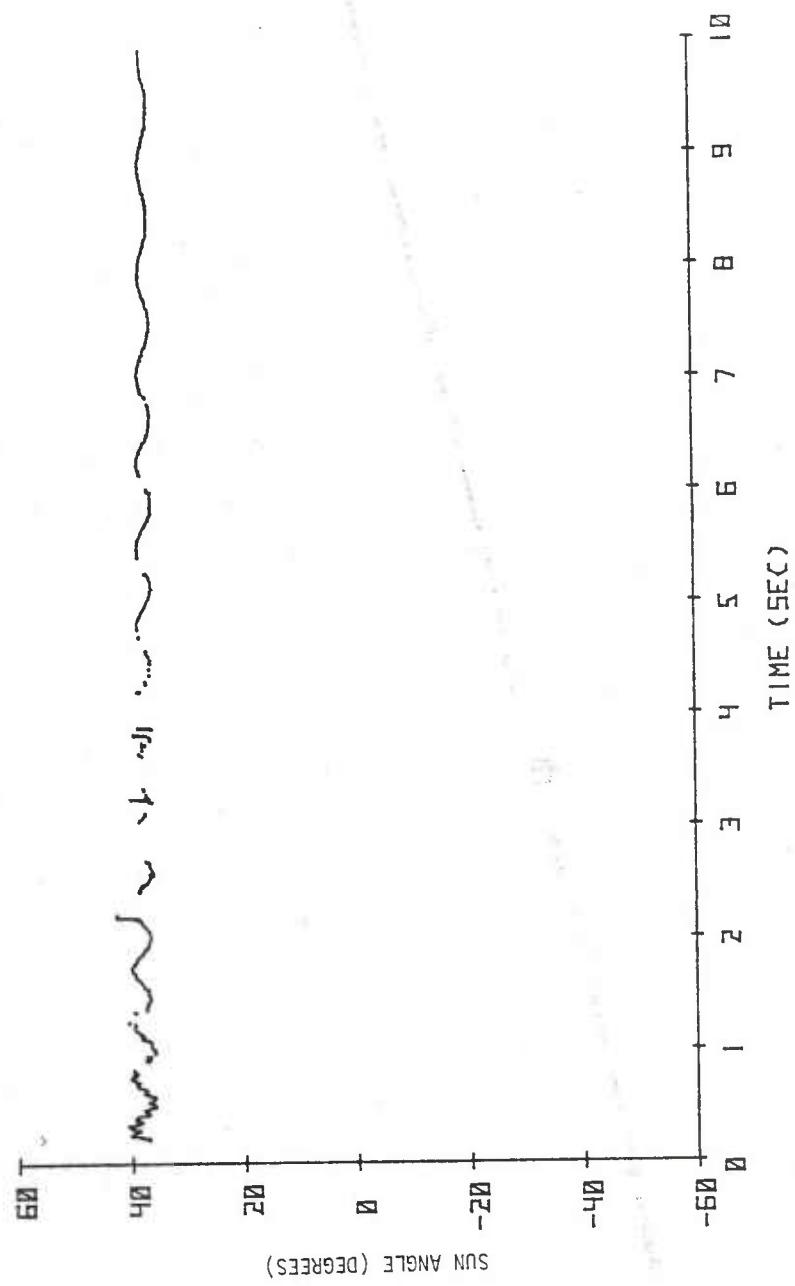


Figure 18. The Yawing Motion of the NCB-A Projectile Round No. 6

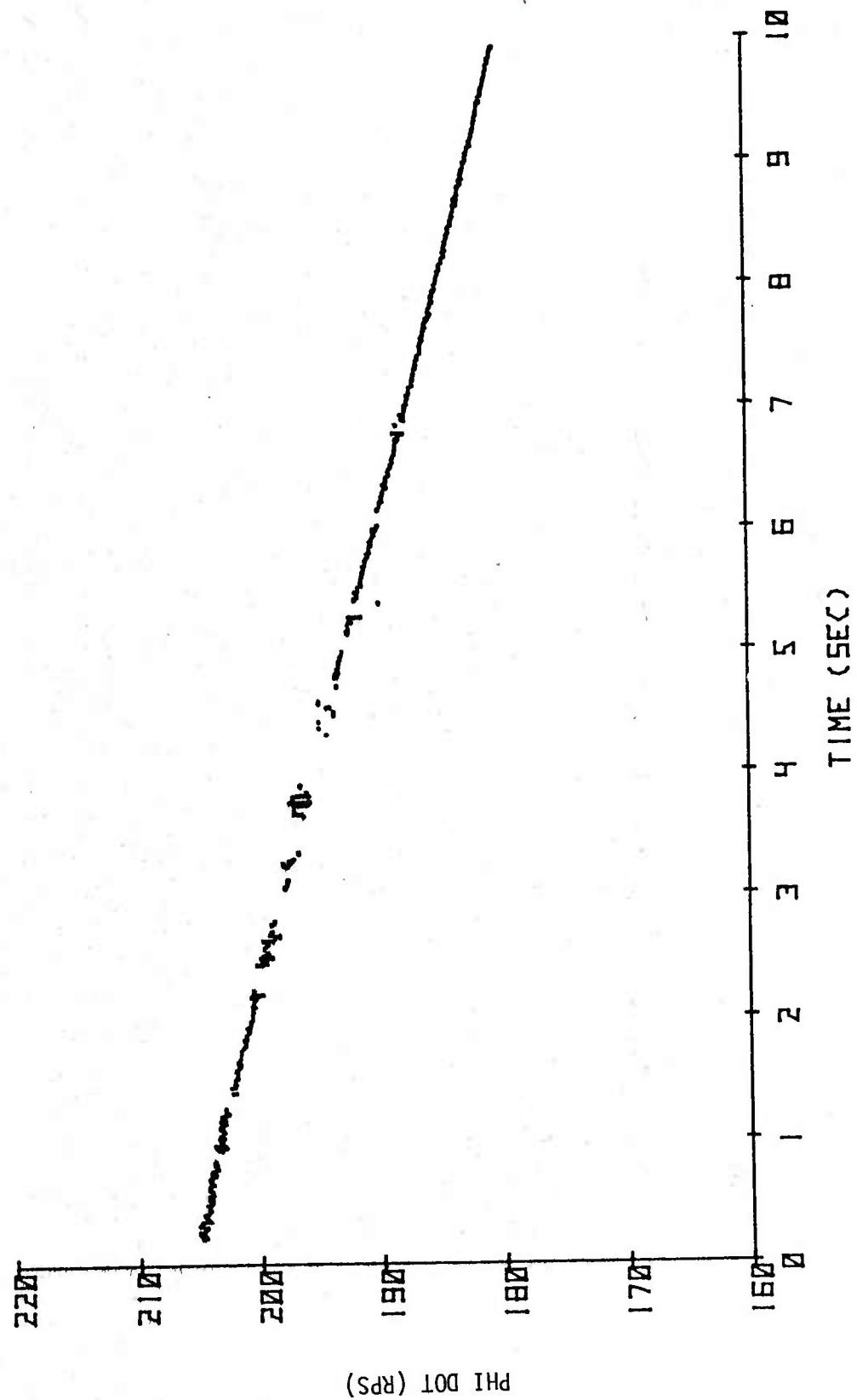


Figure 19. The Spin Motion of the NCB-A Projectile Round No. 6

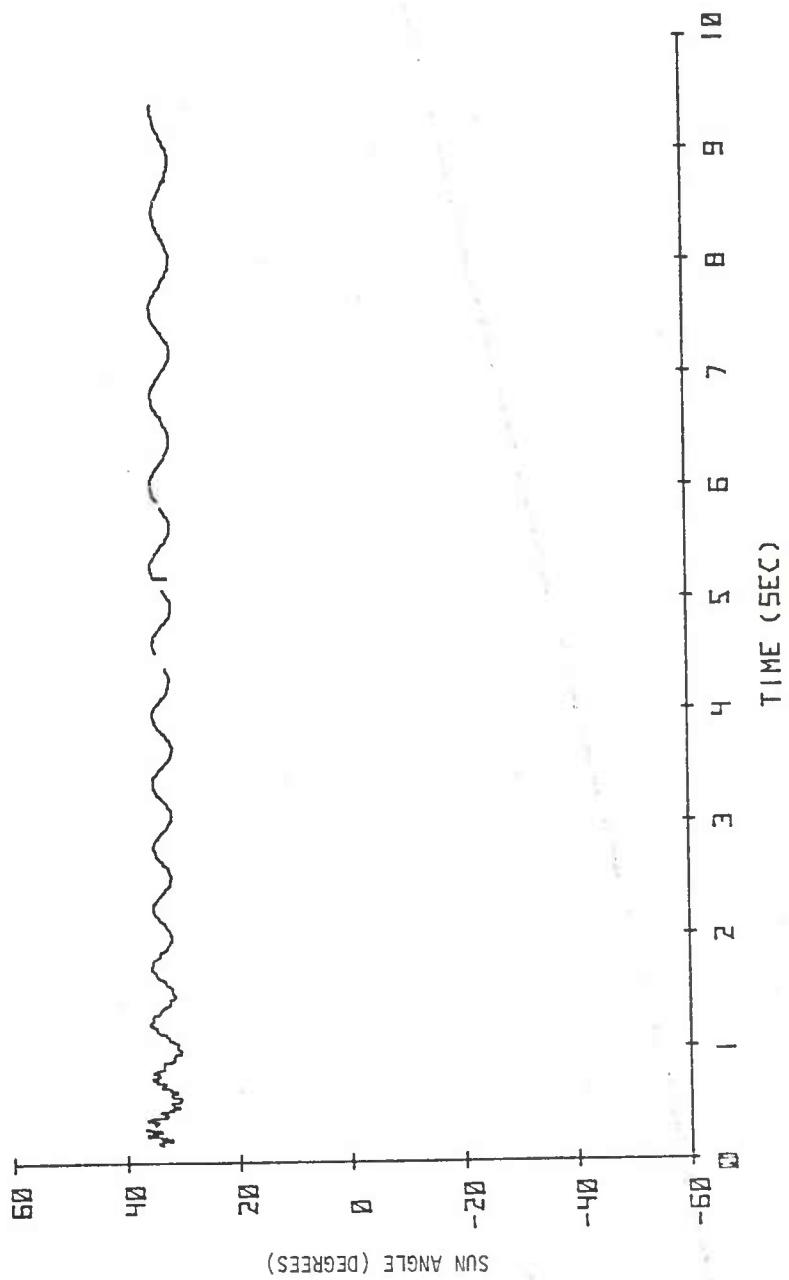


Figure 20. The Yawing Motion of the NCB-A Projectile Round No. 7

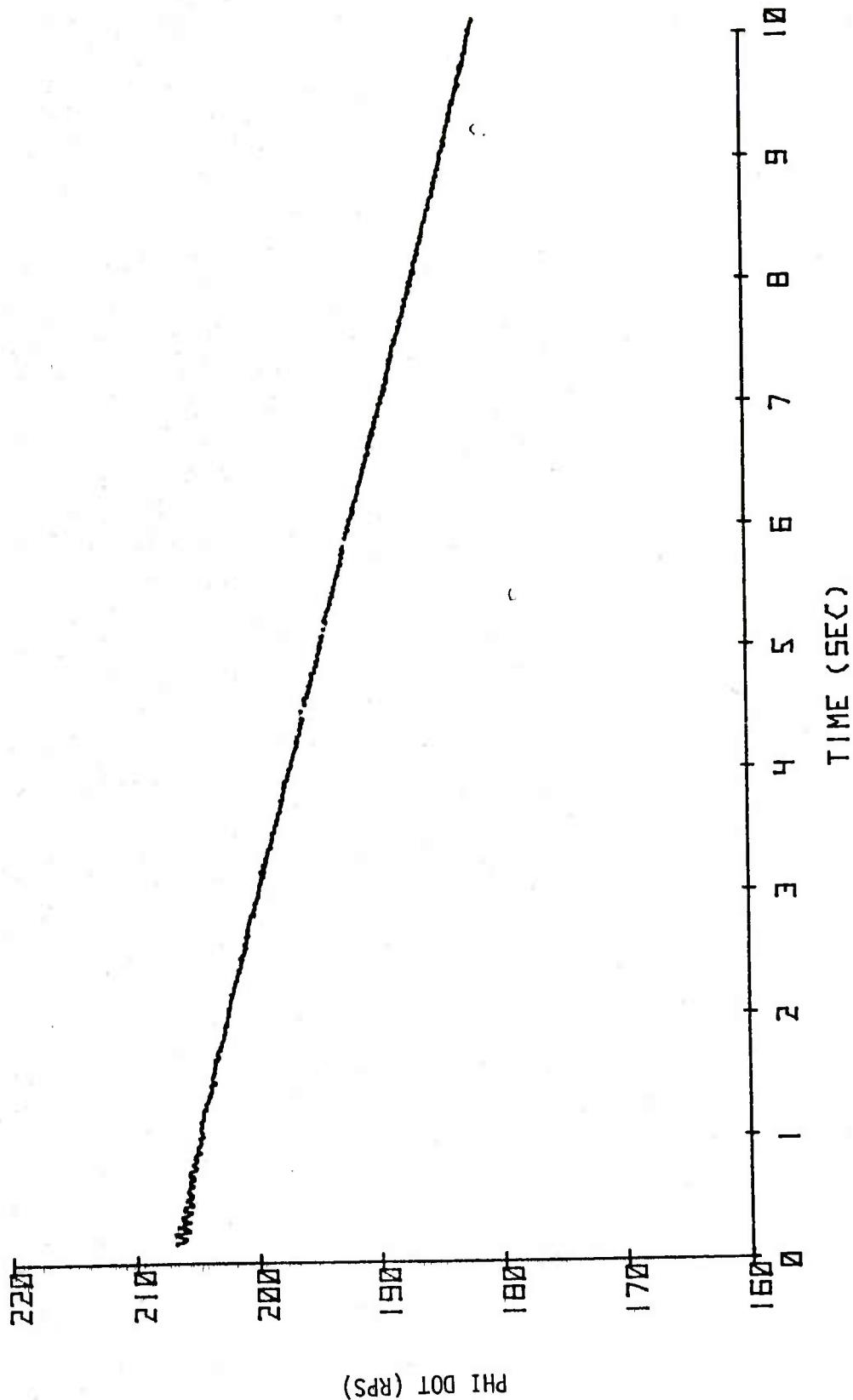


Figure 21. The Spin Motion of the NCB-A Projectile Round No. 7

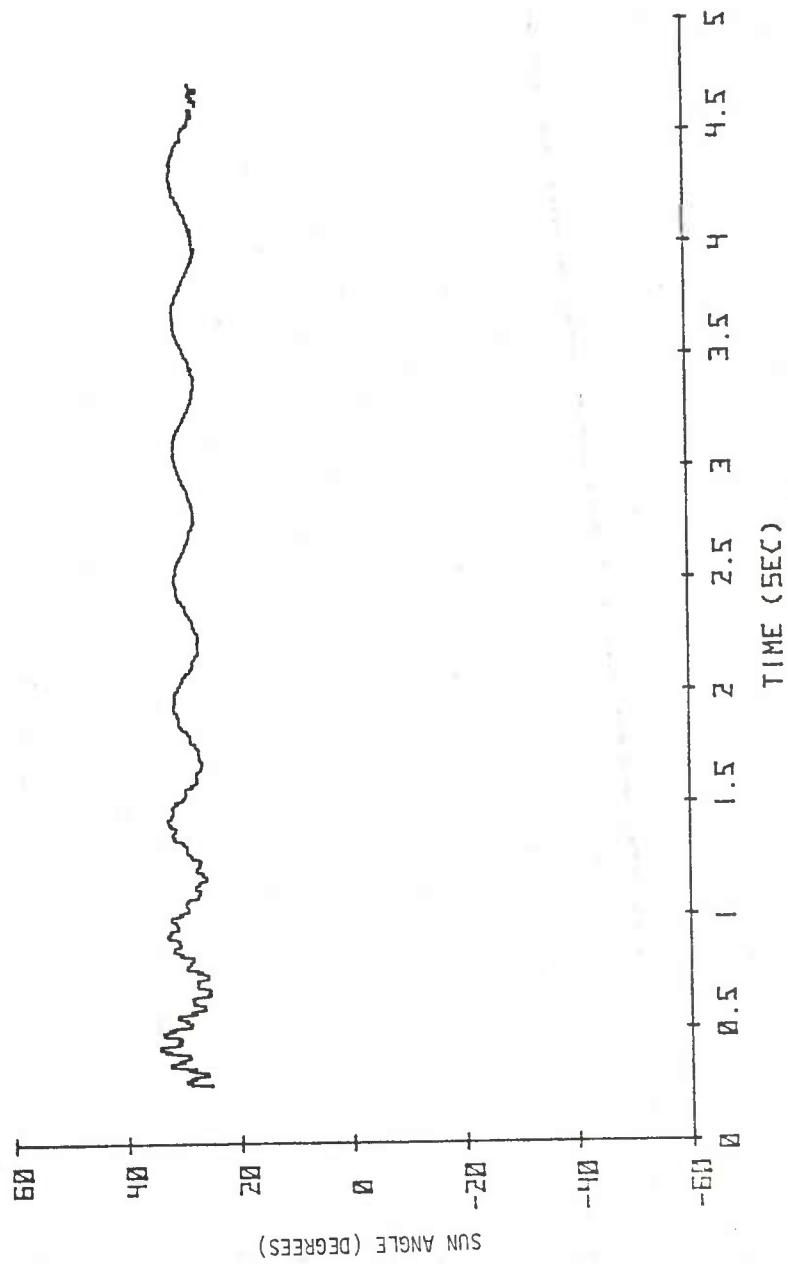


Figure 22. The Yawing Motion of the NCB-A Projectile Round No. 8

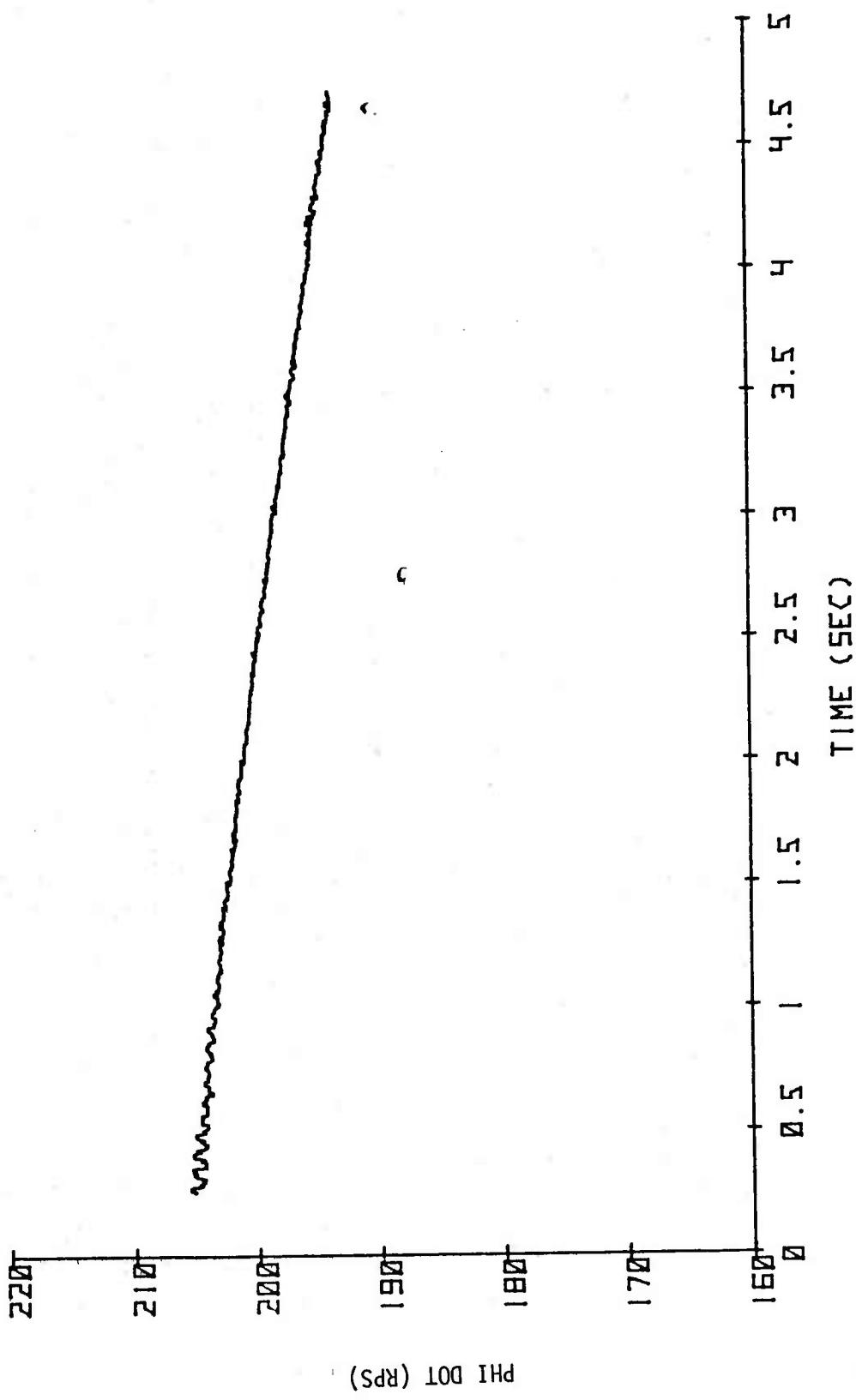


Figure 23. The Spin Motion of the NCB-A Projectile Round No. 8

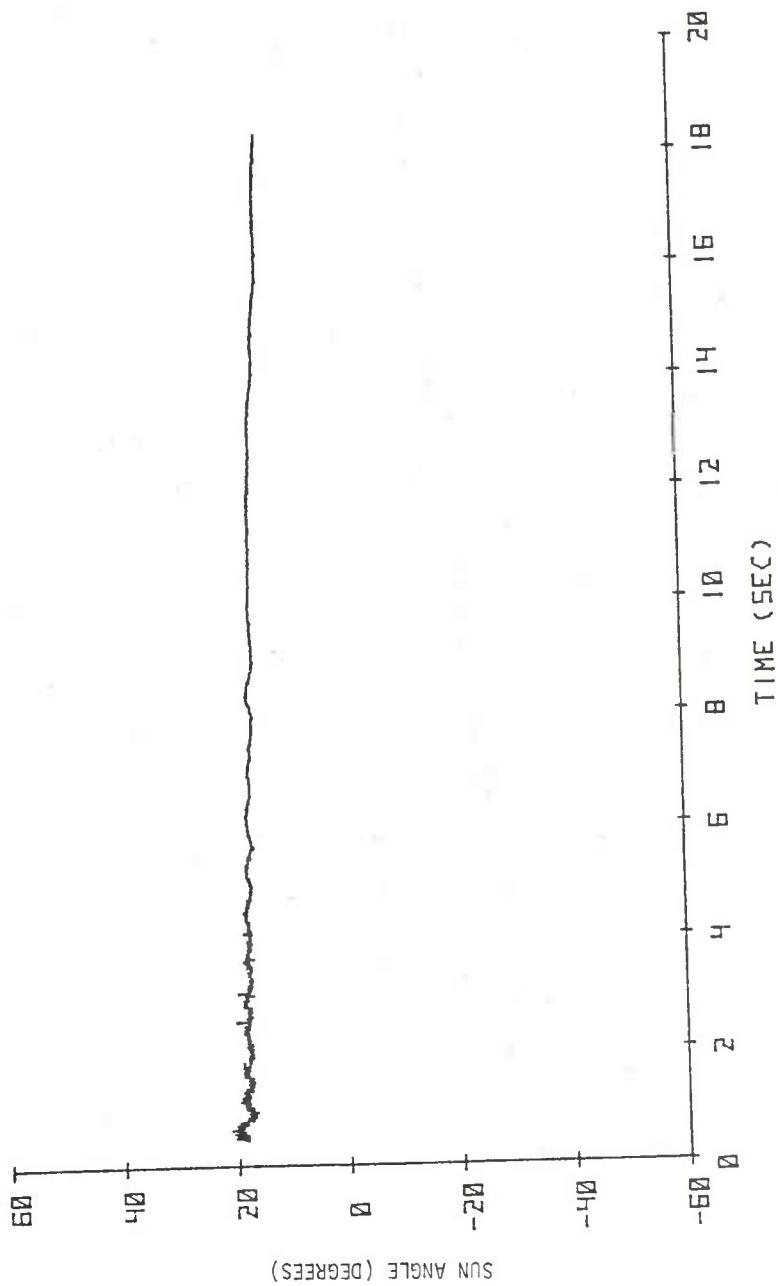


Figure 24. The Yawing Motion of the M549 RAP Projectile, Rocket Off, Round No. 10

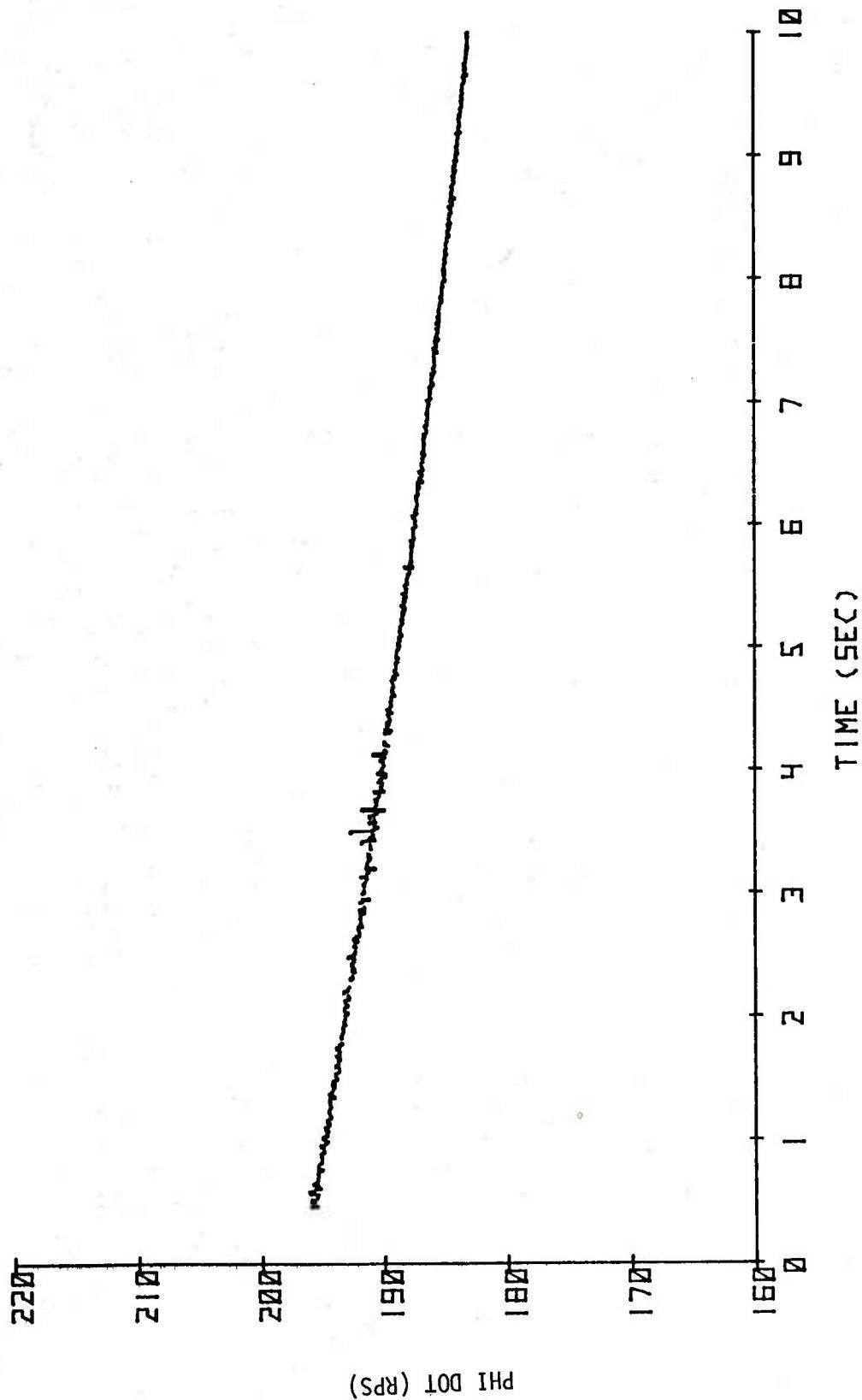


Figure 25. The Spin Motion of the M549 RAP Projectile, Rocket Off, Round No. 10

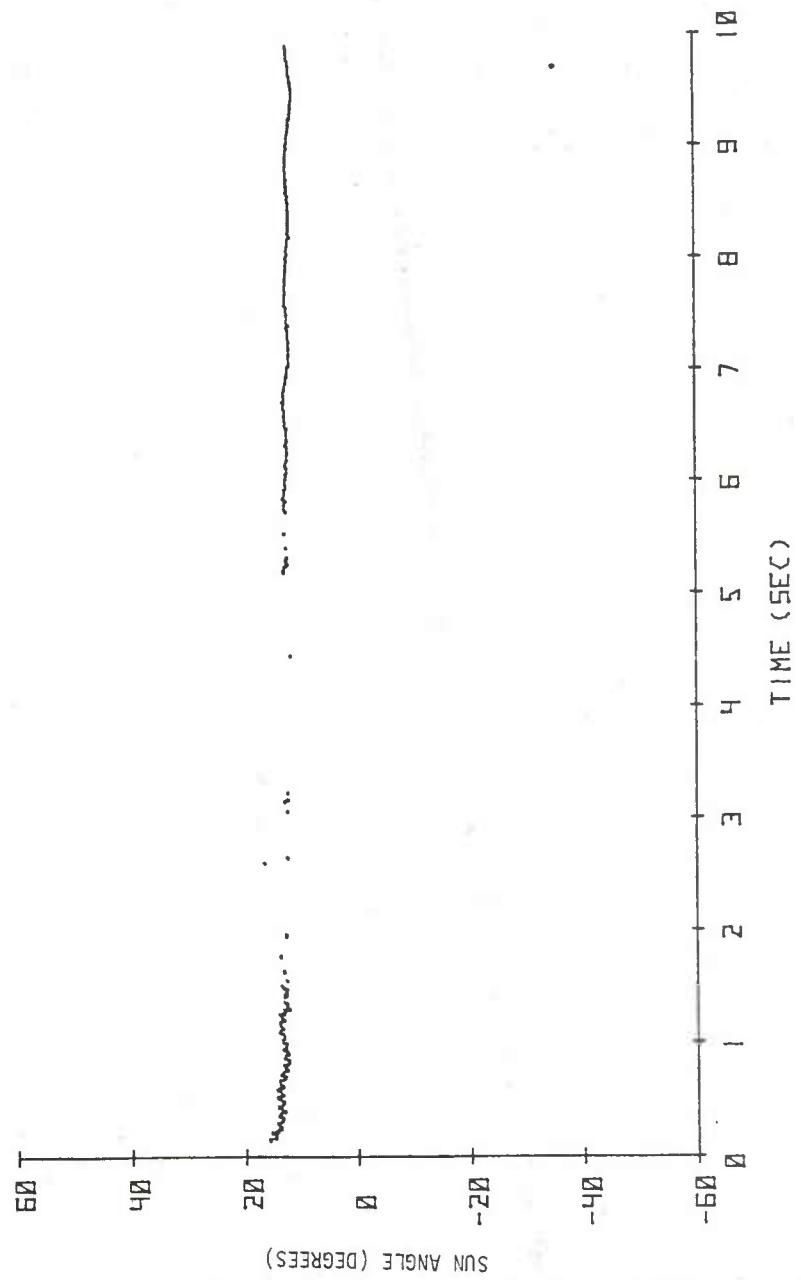


Figure 26. The Yawing Motion of the M549 RAP Projectile, Rocket Off, Round No. 11

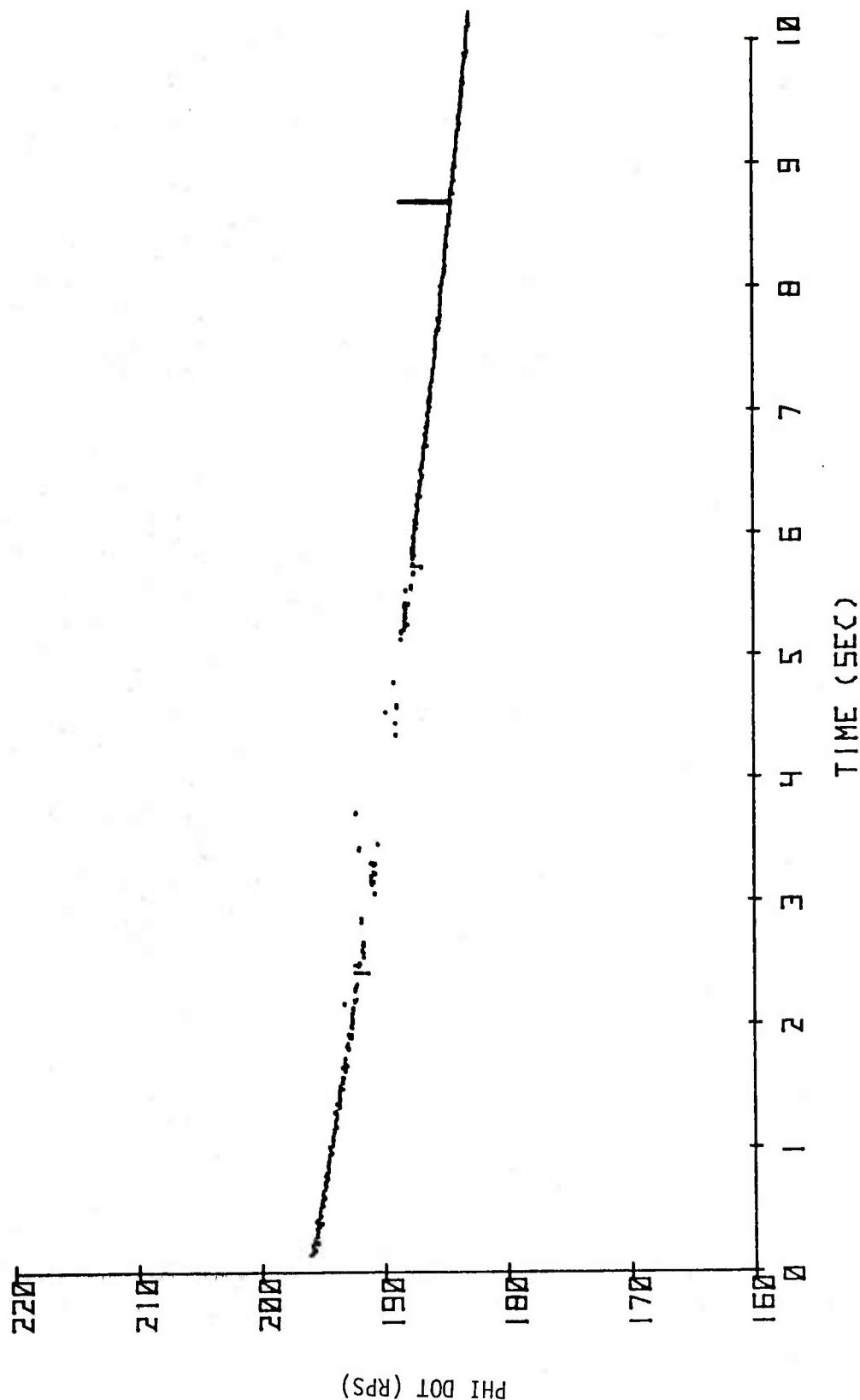


Figure 27. The Spin Motion of the M549 RAP Projectile, Rocket Off, Round No. 11

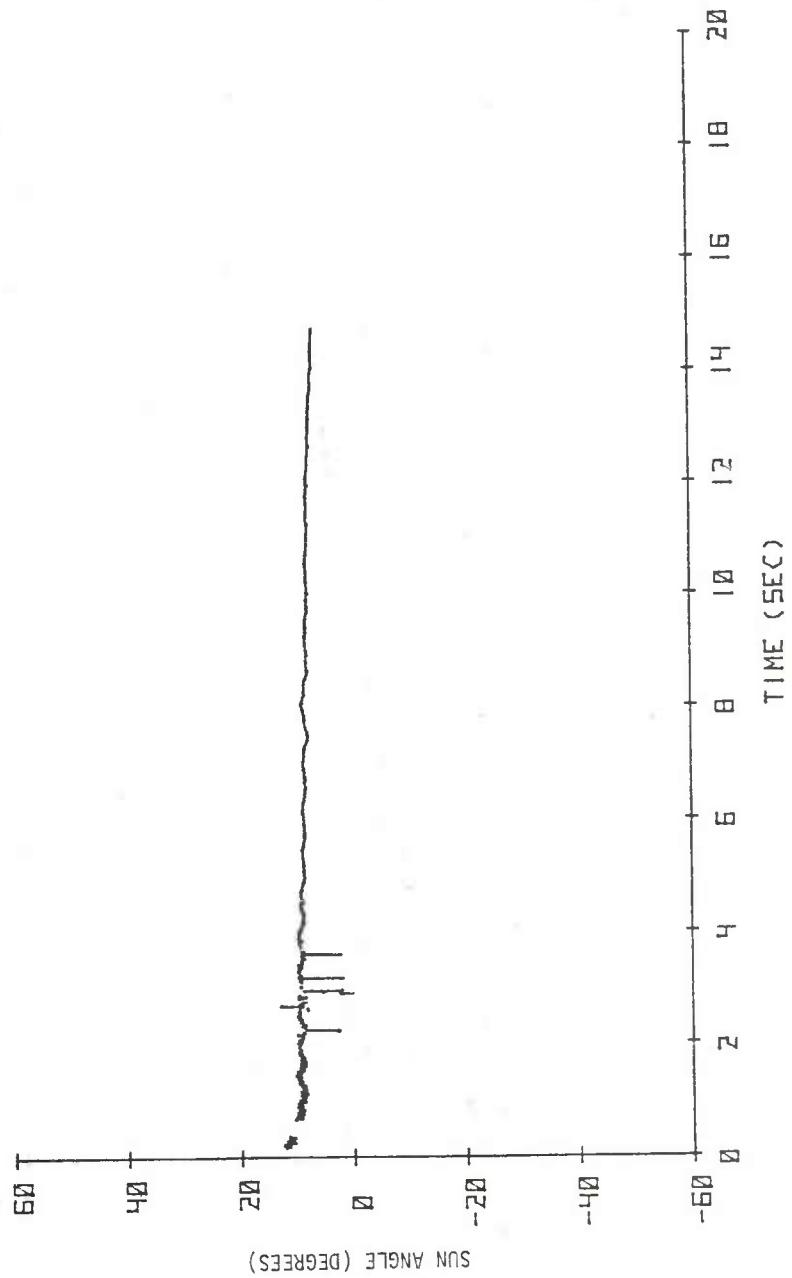


Figure 28. The Yawing Motion of the M549 RAP Projectile, Rocket Off, Round No. 13

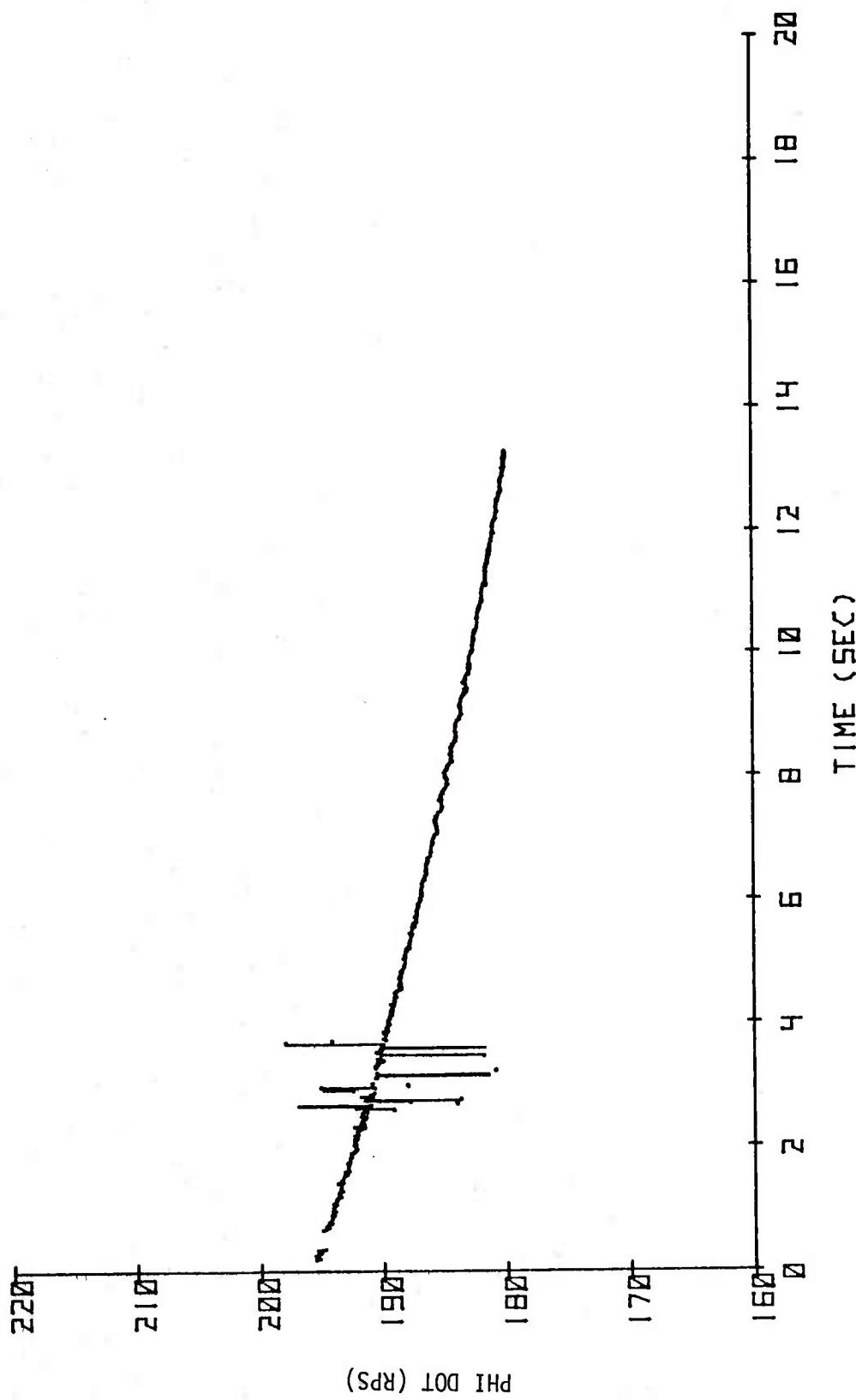


Figure 29. The Spin Motion of the M549 RAP Projectile, Rocket Off, Round No. 13

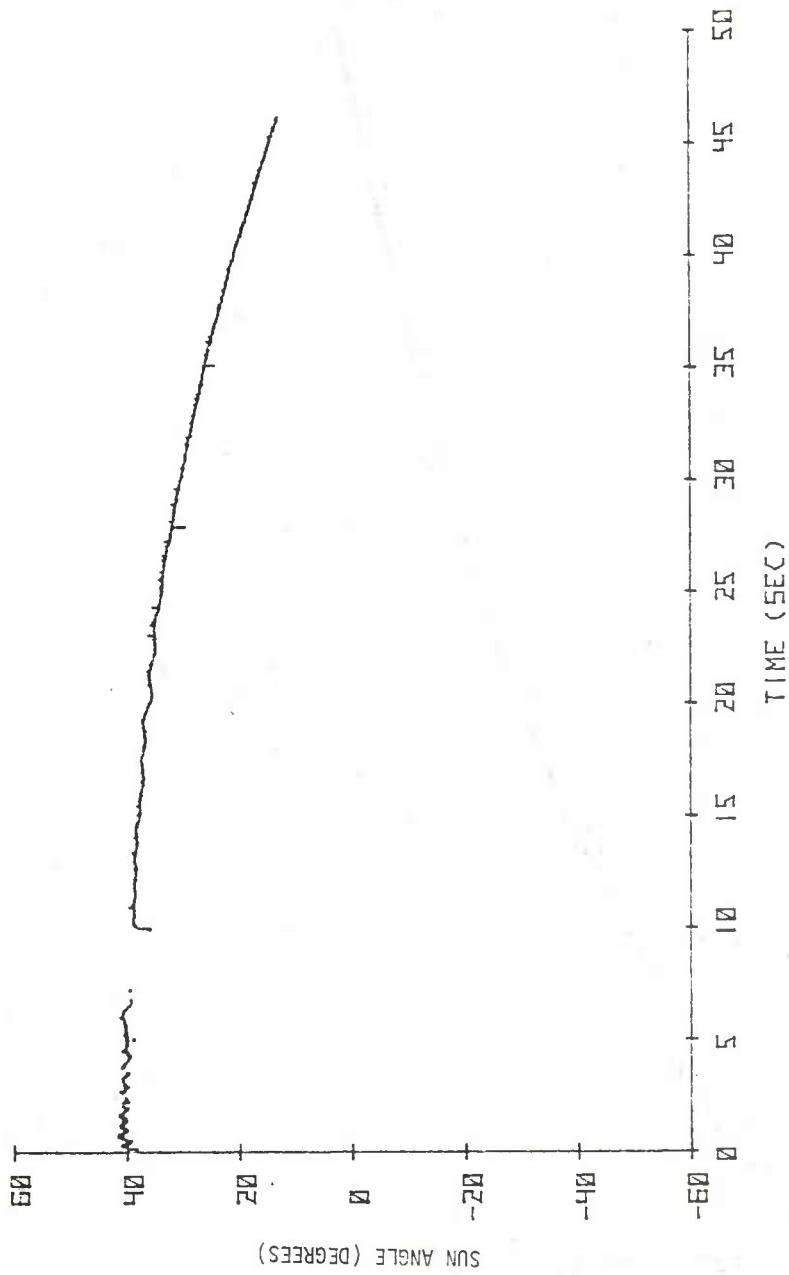


Figure 30. The Yawing Motion of the M549 RAP Projectile, Rocket On, Round No. 15

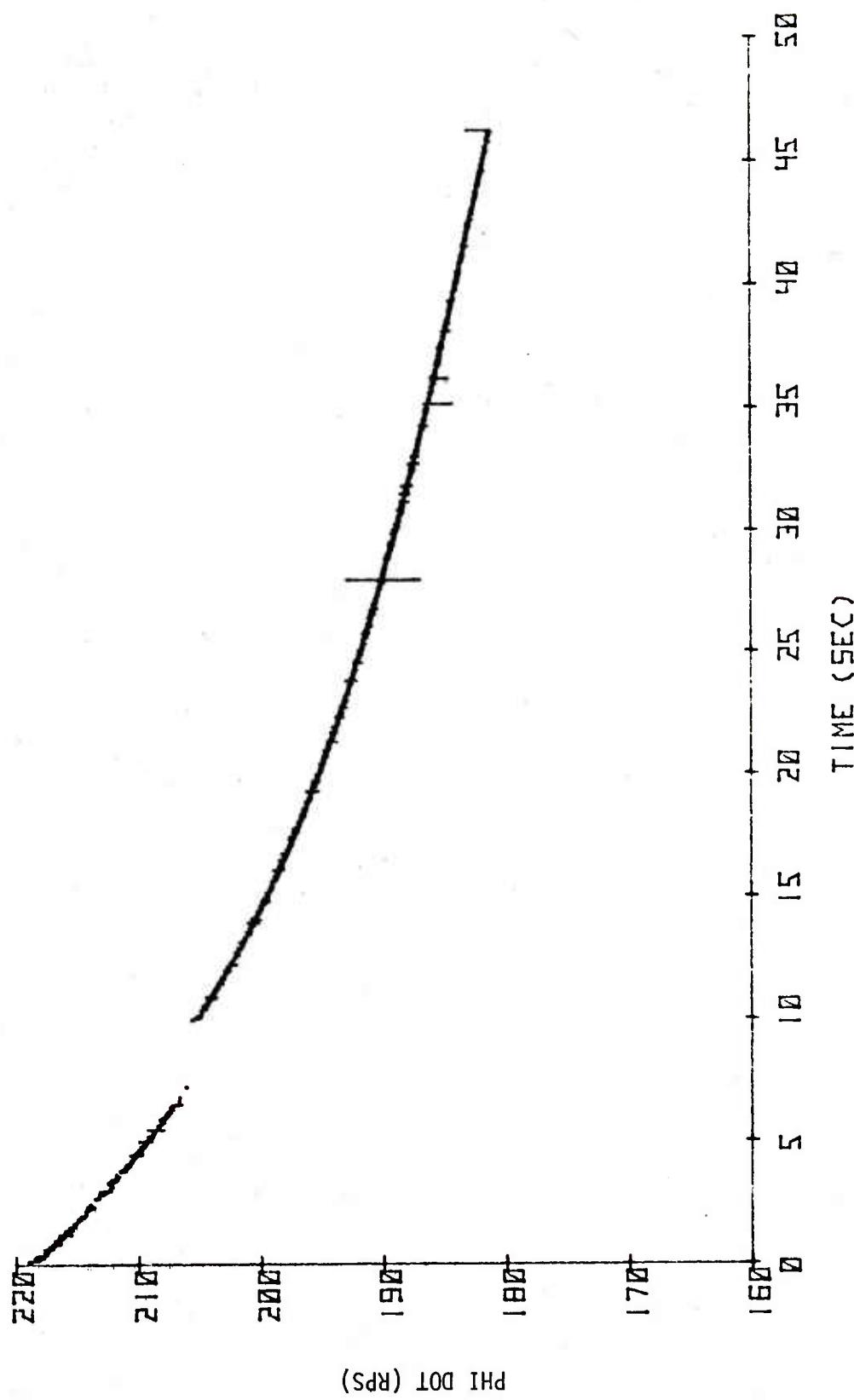


Figure 31. The Spin Motion of the M549 RAP Projectile, Rocket On, Round No. 15

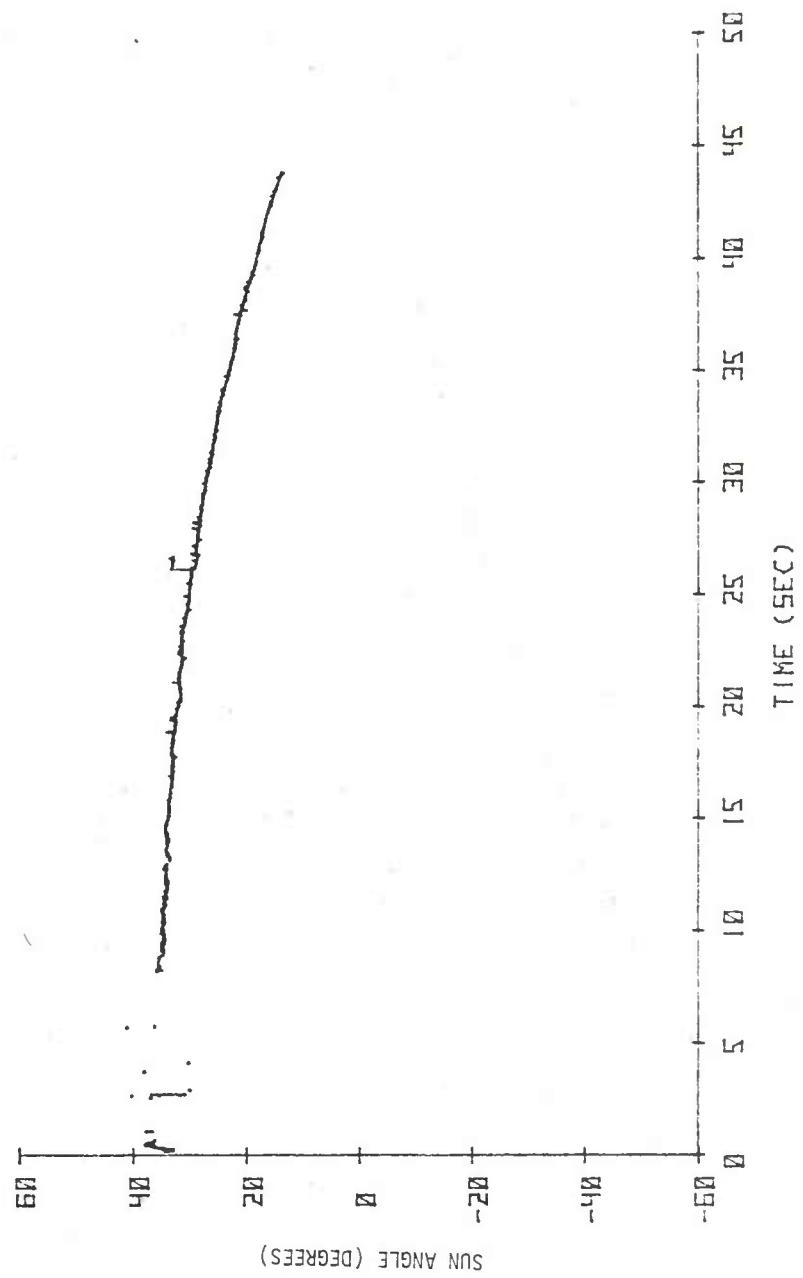


Figure 32. The Yawing Motion of the M549 RAP Projectile, Rocket On, Round No. 16

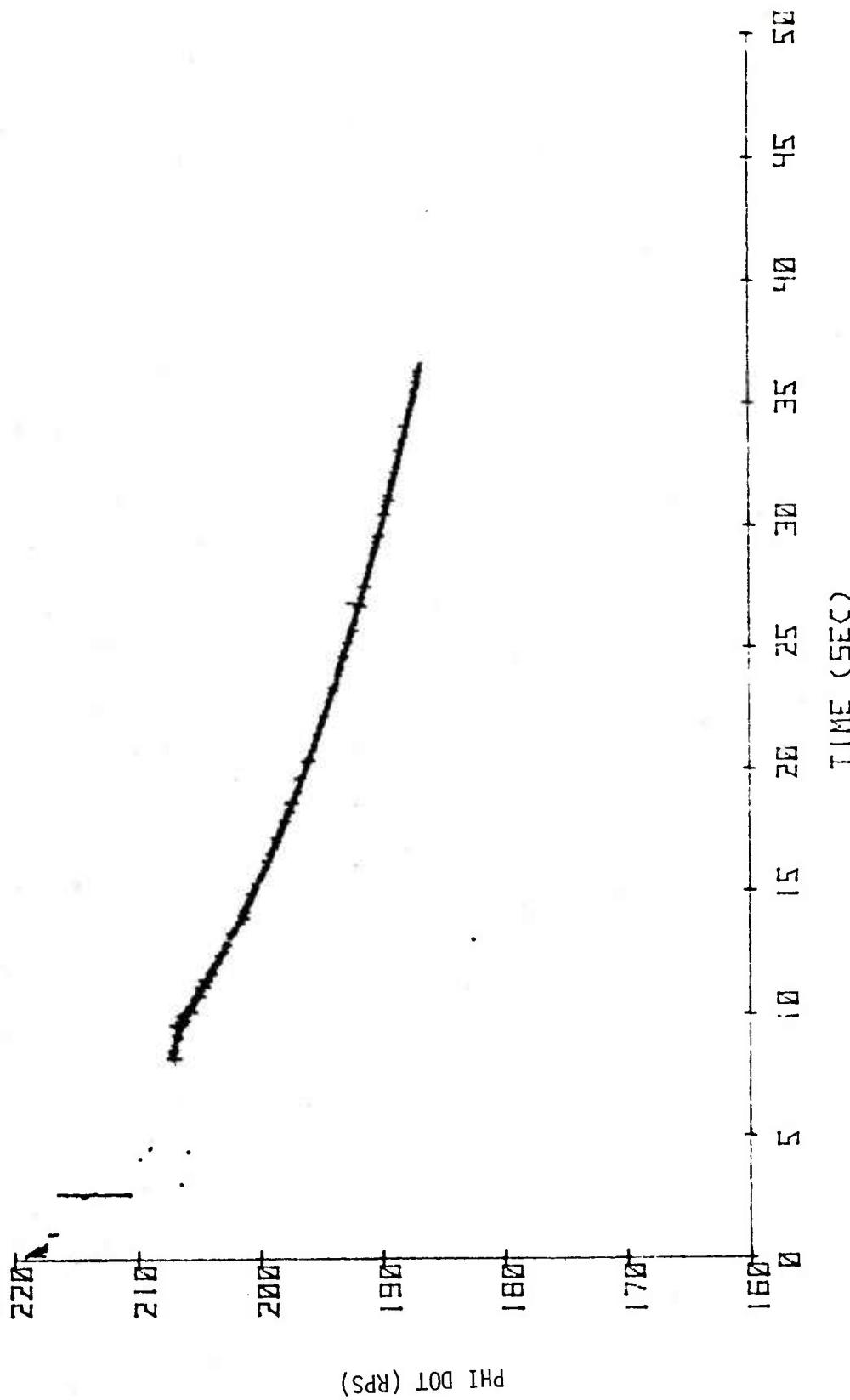


Figure 33. The Spin Motion of the M549 RAP Projectile, Rocket On, Round No. 16

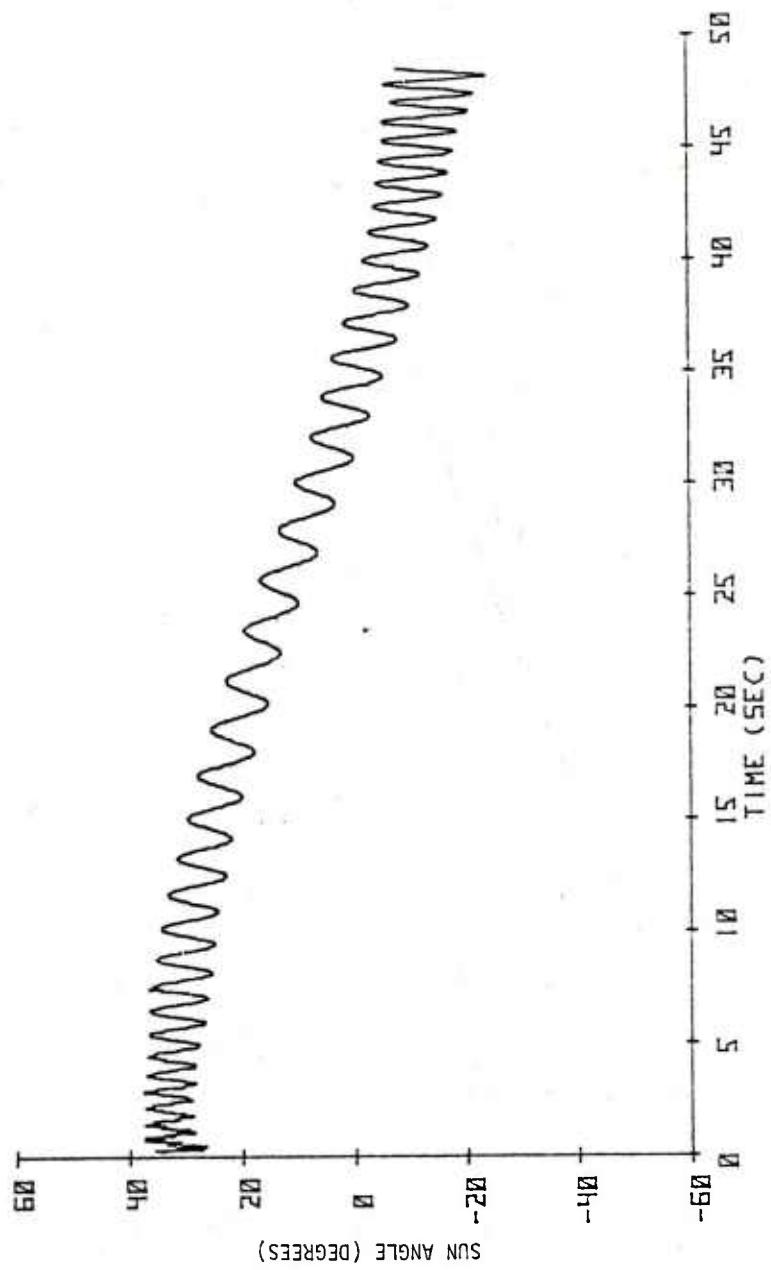


Figure 34. The Yawing Motion of the NCB-B Projectile Round No. 17

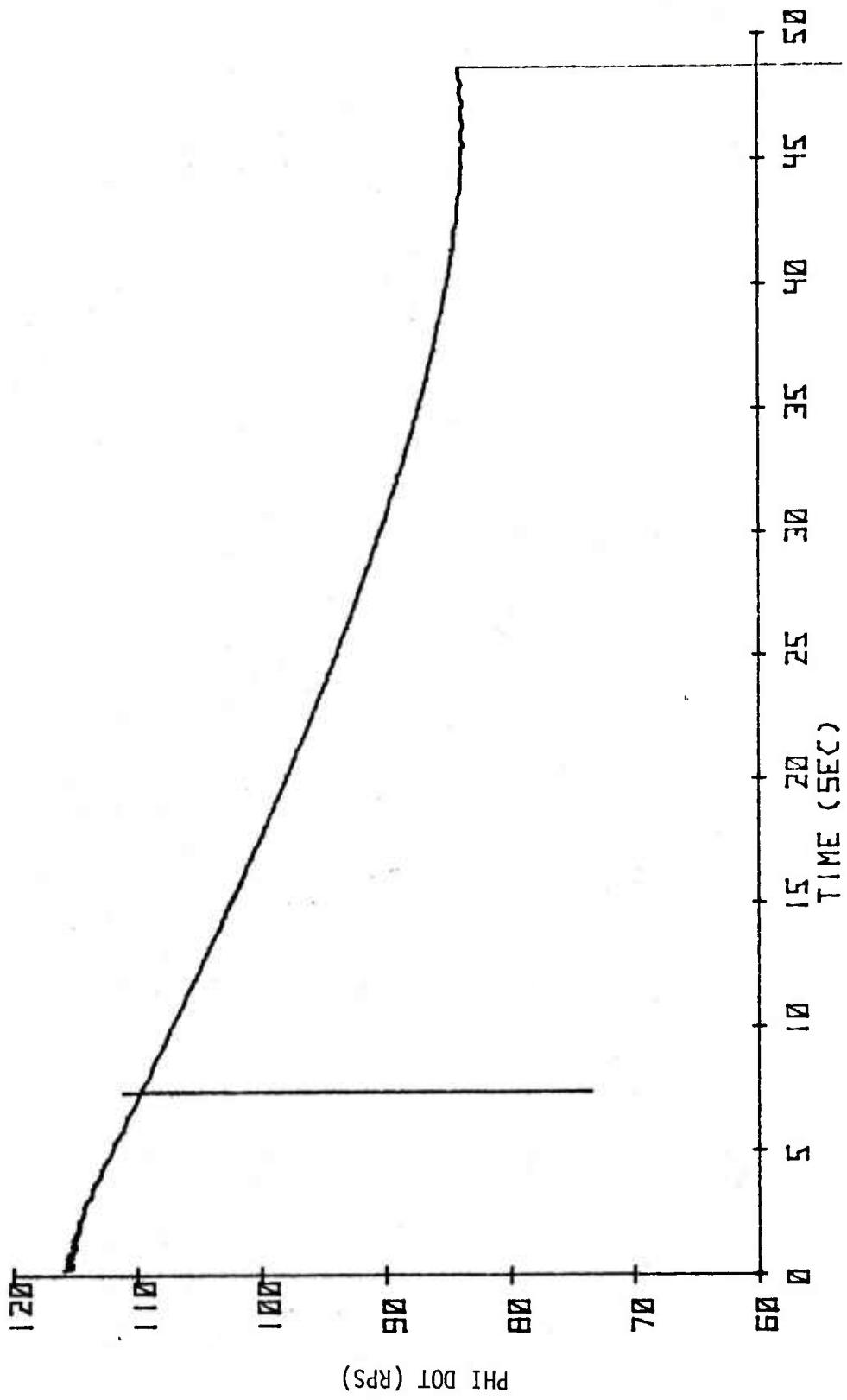


Figure 35. The Spin Motion of the NCB-B Projectile Round No. 17

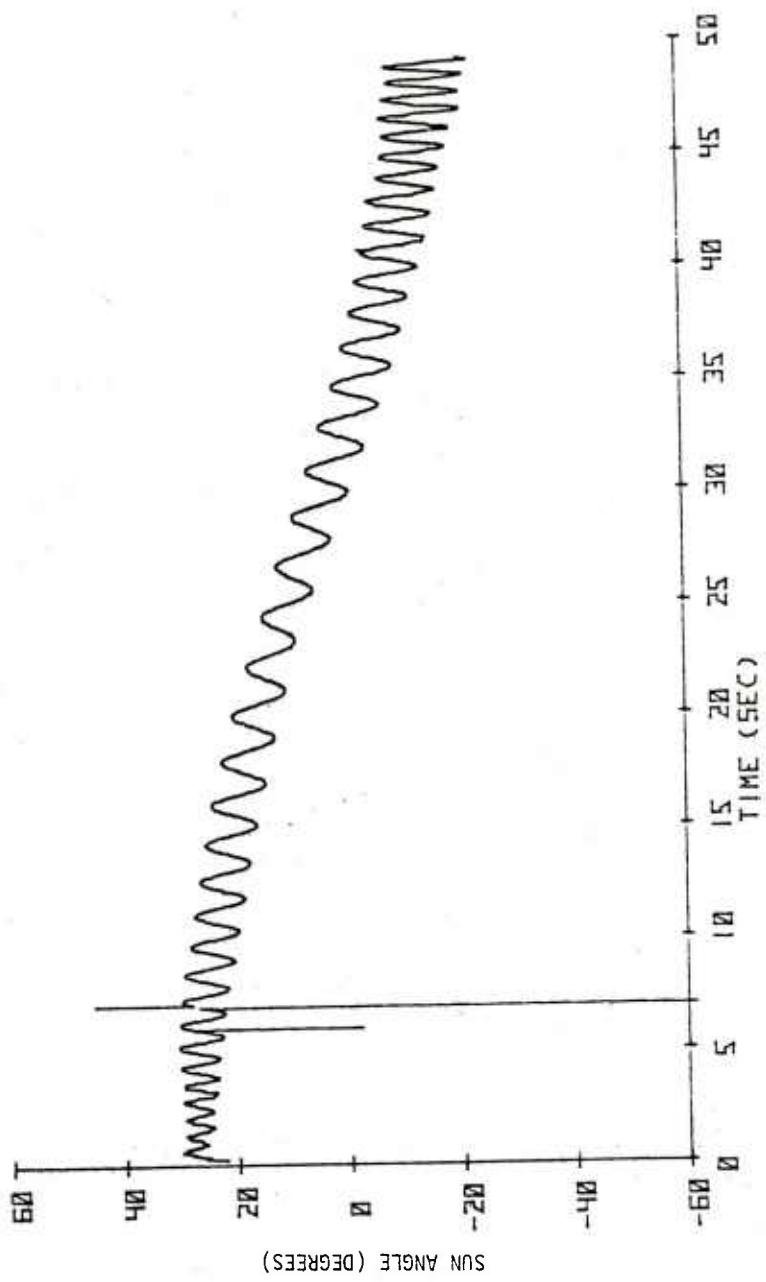


Figure 36. The Yawing Motion of the NCB-B Projectile Round No. 18

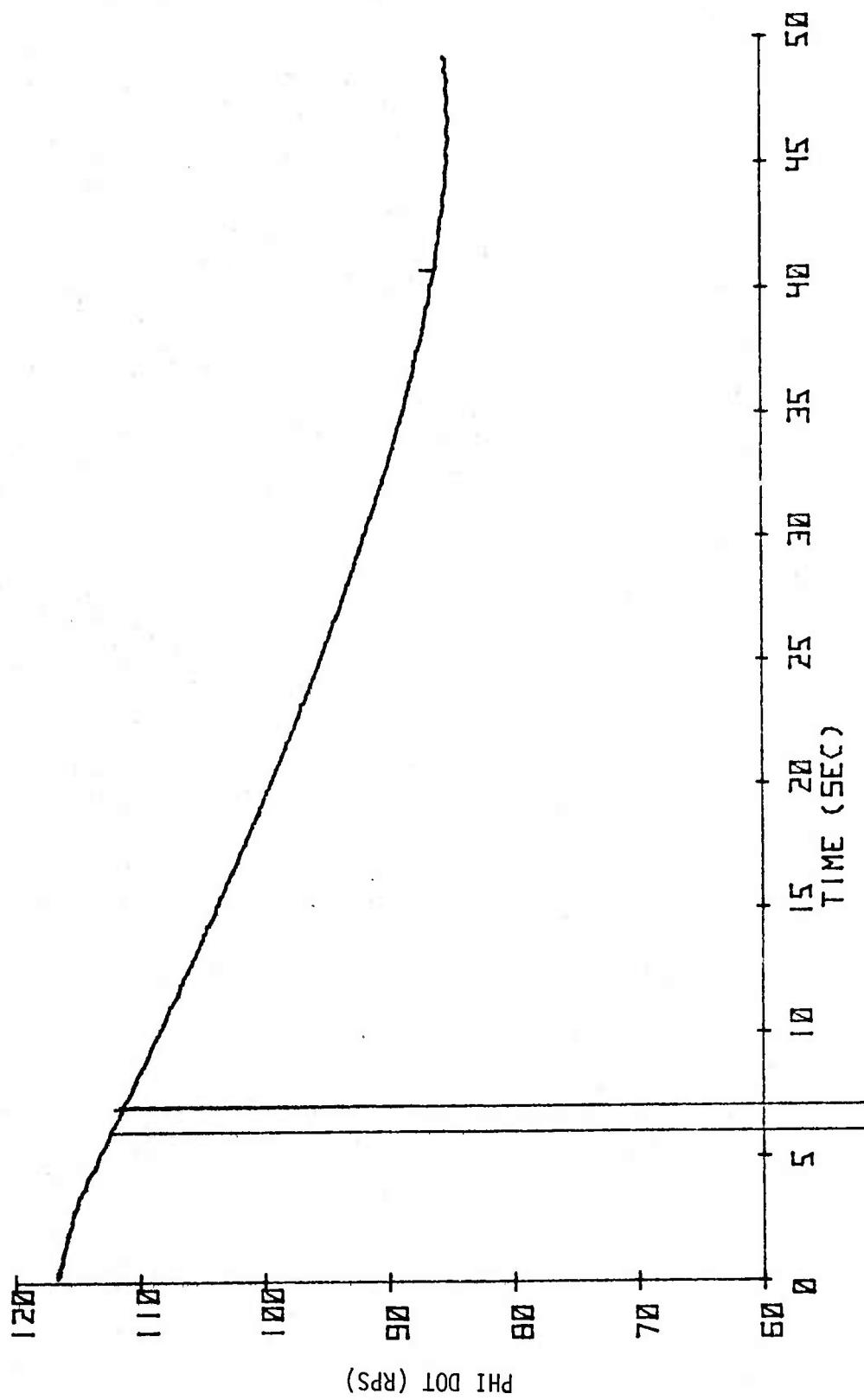


Figure 37. The Spin Motion of the NCB-B Projectile Round No. 18

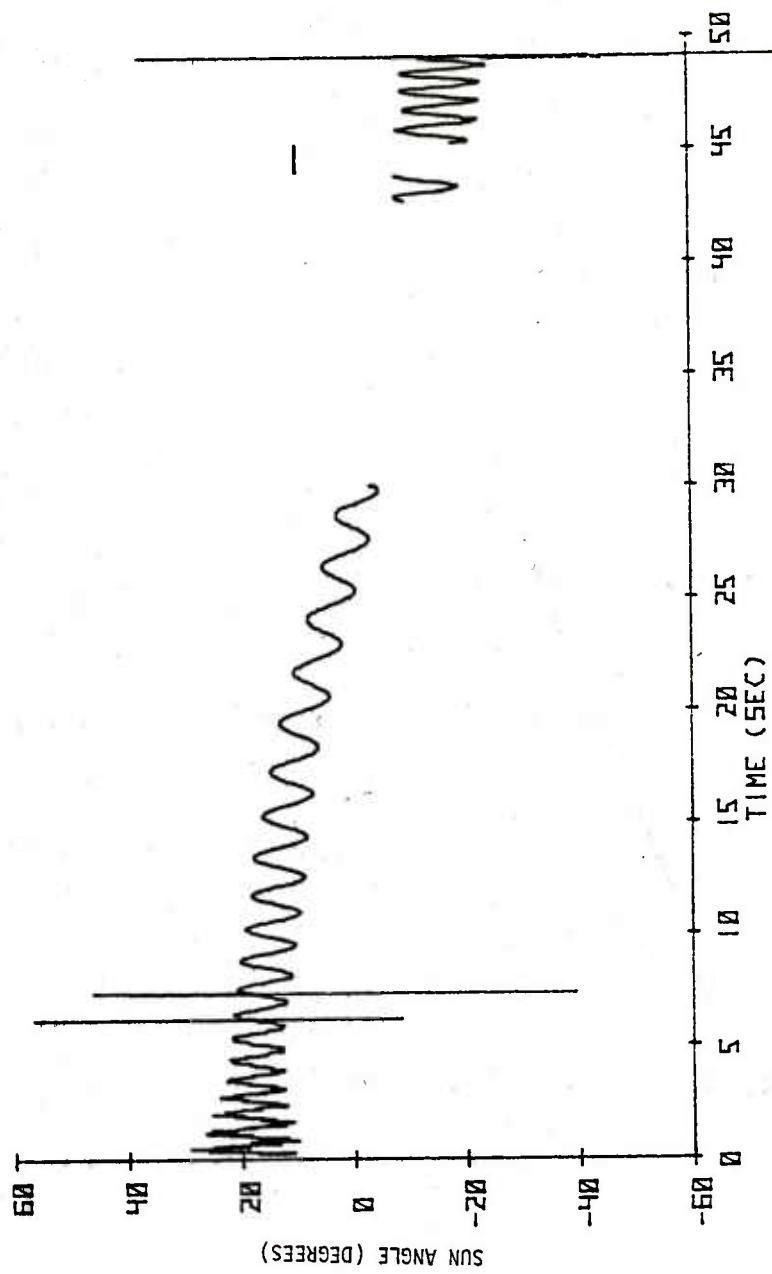


Figure 38. The Yawing Motion of the NCB-B Projectile Round No. 19

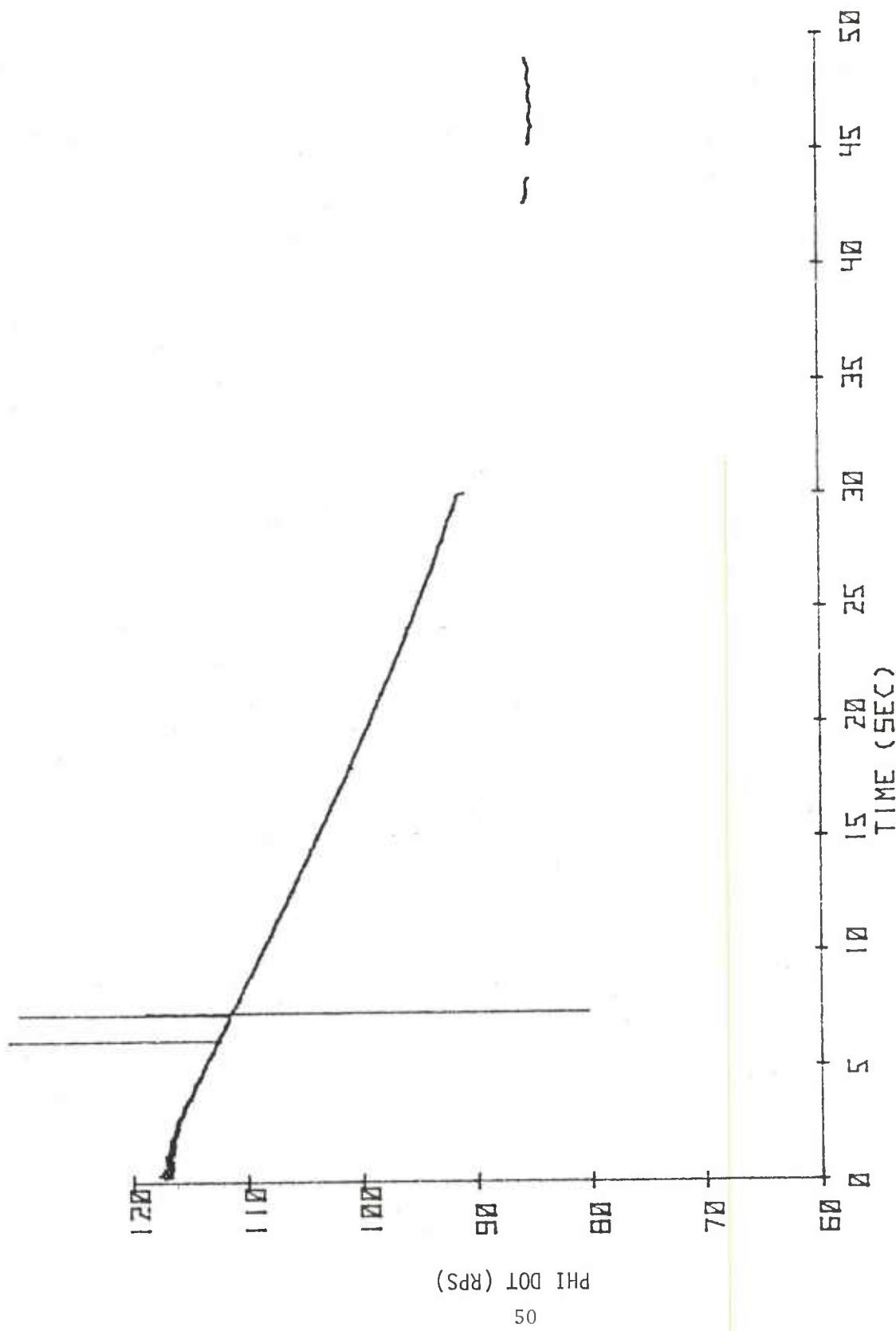


Figure 39. The Spin Motion of the MCB-B Projectile Round No. 19

Table I. The Physical Characteristics of the 155 mm Projectiles
Fired at Tonopah Test Range, Nevada, on 18-21 October 1977

<u>Configuration</u>	<u>W kg.</u>	<u>C.G. Cal. Aft Nose</u>	<u>I_x kg·m²</u>	<u>I_y kg·m²</u>
NCB-A	43.0	3.5	.130	1.710
M549	43.5	3.5	.150	1.930
NCB-B	46.1	3.9	.122	1.695

Table II. Program for the Second Phase Shoot of the NCB-A and NCB-B Projectiles at Tonopah During the Week of 17 October 1977

<u>Round</u>	<u>Number of Projectiles</u>	<u>Mach No. at Launch</u>	<u>Charge</u>	<u>Comments</u>
NCB-A	9	1.8	XM201E2 (Z6)	Yawsonde Records and Flight Behavior
M549	5	1.8	XM201E2 (Z6)	Yawsonde Records and Flight Behavior
M549	2	Maximum Range RAP On	XM201E2 (Z7)	Yawsonde Records and Flight Behavior
NCB-B	2	1.05	M3A1 (25 and 50Z)	Yawsonde Records Boattail Pads
NCB-B	2	1.05	M3A1 (25 and 50Z)	Yawsonde Records No Boattail Pads Plus $\frac{1}{2}$ Muzzle Lip

Table III. Log of Second Phase Non-Conical Boattail Projectile Flights
Tonopah Test Range, Nevada, 18 October 1977

Tonopah Round Number	BRL Model Number	BRL Yawsonde Number	Yawsonde Frequency Hertz	Launch Time Hours	Muzzle Velocity m/sec	Breech Pressure kg/cm ²	Telemetry Status in Flight	Smear Camera	Yawsonde Loading ¹ Distance Meters
Non-Conical Boattail Projectile-A (No Plastic Obturator Ring)									
422276-1	B4778	1302	241.0	1316	642.3	1900	Recorded	No	.756
-2	B4776	1300	238.9	1331	659.3	2020	"	"	.759
-3	B4777	1298	247.0	1344	648.3	1980	"	"	.762
-4	B4779	1294	244.8	1357	645.6	1980	"	"	"
-5	B4783	1296	242.1	1408	646.2	1980	"	"	"
-6	B4780	1299	239.0	1429	644.3	1980	"	"	"
-7	B4784	1062	245.1	1439	648.7	1940	"	"	"
-8	B4781	974	242.8	1450	643.8	1900	Noisy	"	"
-9	B4782	1279	239.1	1503	642.9	1880	No	"	"
M549 Projectile With RAP Off (Plastic Obturator Ring)									
422276-10	3	1058	246.6	1556	615.3	1650	Recorded	No	.987
-11	10	1059	244.3	1610	613.2	1640	"	"	"
-12	4	1060	247.5	1620	609.3	1640	No ²	"	"
-13	9	1061	245.3	1634	613.5	1660	Recorded	"	"
-14	11	965	246.0	1644	613.7	1640	No ²	"	"

All rounds fired from M185 gun tube mounted on Tonopah stationary mount with muzzle brake. Gun elevation 1630.4m above mean sealevel, Q.E. = 45°. All rounds fired with charge XM201E2 Zone 6-- flash reducer removed.

Table III. (Continued) Test Firings on 21 October 1977

Tonopah Round Number	BRL Model Number	BRL Yawsonde Number	Yawsonde Frequency Hertz	Launch Time Hours	Muzzle Velocity km/sec	Breech Pressure kg/cm ²	Telemetry Status in Flight	Yawsonde Camera	Smear Camera	Loading ¹ Distance Meters

One Warmer Round -- 155mm 107 Projectile -- No Data Taken

M549 Projectile With RAP On (Plastic Obturator Ring)

422276-15	6	1207	235.1	1413	683.7	2540	Recorded	Yes	.984
-16	7	1209	237.2	1426	685.2	2570	"	"	"

Charge for above rounds XM201E2 Zone 7 -- RAP on from 7 seconds to 10 seconds.

Non-Conical Boattail Projectile-B With Boattail Pads--Full Muzzle Brake Plastic Discarding Rotating Band--Charge M3A1 Zone 5 + 5 Oz.

422276-17	B4867	1301	243.7	1441	365.5	1090	Recorded	Yes	1.022
-18	B4869	1297	244.2	1501	367.4	1110	"	"	"

Non-Conical Boattail Projectile-B No Boattail Pads--½ Muzzle Brake Plastic Discarding Rotating Band--Charge M3A1 Zone 5 + 5 Oz.

422276-19	B4870	1295	244.1	1534	364.0	1090	Recorded	Yes	1.026
-20	B4868	1032	239.1	1549	363.9	1080	No	"	"

All rounds fired from M185 gun tube mounted on Tonopah stationary mount. Gun elevation 1650.4m above mean sealevel, Q.E. = 45°.

1 -- Distance from projectile base to end of open breech.

2 -- Yawsonde fuze was tight fit in projectile cavity. Battery cap may have unscrewed so that battery power was lost.

Table IV. The Impact Data From the Phase 2 Flights

Round	Range m	Deflection to Right m	Muzzle Velocity m/sec	Range Corrected to V = 650 m/sec m	Dispersion
422276-1	20,137.5	383.1	642.3	20,388	
-2	20,467.6	337.8	<u>651.0-659.3*</u>	20,151	
-3	20,411.1	284.9	<u>648.3</u>	20,461	
-4	20,296.5	311.3	645.6	20,435	
-5	20,337.0	320.6	646.2	20,461	
-6	20,306.5	350.0	644.3	20,492	Without Rounds 2 and 7
-7	20,386.4	345.0	<u>644.8-648.7*</u>	20,423	Average Range = 20,444.3 m
-8	20,212.9	322.3	<u>643.8</u>	20,414	Standard Deviation = 35.3 m
-9	20,250.0	303.4	642.9	20,480	P.E. = .12%
					Range Corrected to V = 610 m/sec
-10	17,851.3	323.3	615.3	17,626	
-11	17,826.3	358.2	613.2	17,691	Average Range = 17,701.5 m
-12	17,831.2	367.4	609.3	17,856	Standard Deviation = 89.5 m
-13	17,820.6	426.4	613.5	17,673	P.E. = .34%
-14	17,817.7	426.8	613.7	17,662	
-15	Not Recorded		683.7		
-16	Not Recorded		685.2		
-17	10,723.9	472.9	365.5		Two of these rounds were
-18	10,704.2	632.3	367.4		fired with induced yaw.
-19	10,739.5	410.1	364.0		Data was not good for
-20	10,734.6	355.6	363.9		dispersion.

* Velocimeter data questionable--either velocity is possible. Underlined velocities maintain
P.E. = .12%.

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